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STUDIES ON OAT BREEDING. IV—PURE LINE VARIETIES

CONTENTS.

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BULLETIN 250.

STUDIES ON OAT BREEDING. IV. PURE LINE VARIETIES.[1]

By

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The agricultural importance of the oat crop in Maine led the Experiment Station to undertake some definite breeding work with this cereal at Highmoor Farm in 1910. The general outline of this work has been given in a previous paper.[2] One of the lines of work attempted, has been to develop new varieties which would be better adapted to our conditions than any of those now grown. In attempting to do this several methods have been employed. One of these has been the isolation of "pure lines" out of certain standard commercial varieties. This work has now reached such a point that a discussion of the results may be undertaken.

Before proceeding to the discussion of these "pure lines" it is important to have a clear understanding of what is meant by this term. This term was first used by the Danish botanist, Johannsen. According to Johannsen's[3] definition a "pure line" is the offspring of a single, self-fertilized, homozygous individual. The exact meaning of this can perhaps best be made clear by referring to the work of Johannsen himself.

Johannsen, in his work on beans, brought out very clearly three things which in themselves and in their implications are of fundamental importance to all practical breeders of animals or plants, as well as to students of breeding. These three things are:

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[1]Papers from the Biological Laboratory of the Maine Agricultural Experiment Station No. 96.

[2]Surface, F. M. and Barber, C. W. Studies on Oat Breeding. I. Variety Tests 1910-1913. Maine Agricultural Experiment Station, Ann. Rept. 1914, pp. 137-192. (Bulletin No. 229).

[3]Johannsen, W. Elemente der exakten Erblichkeitslehre. Jena, 1913, pp. XI + 723.

1. That the size of an individual bean was no absolute or certain criterion whatever, as to the average size of its offspring. He found that while some particular large beans always produced large offspring beans, other equally large ones always produced small offspring beans. Some individual small beans produced offspring of large average size, others produced beans of small average size like the parent, and, in general, he showed it to be quite impossible for anyone to tell merely from the size of a bean itself whether its progeny will be large or small.

The nature of Johannsen's results on this point have been clearly set forth in the accompanying diagram.

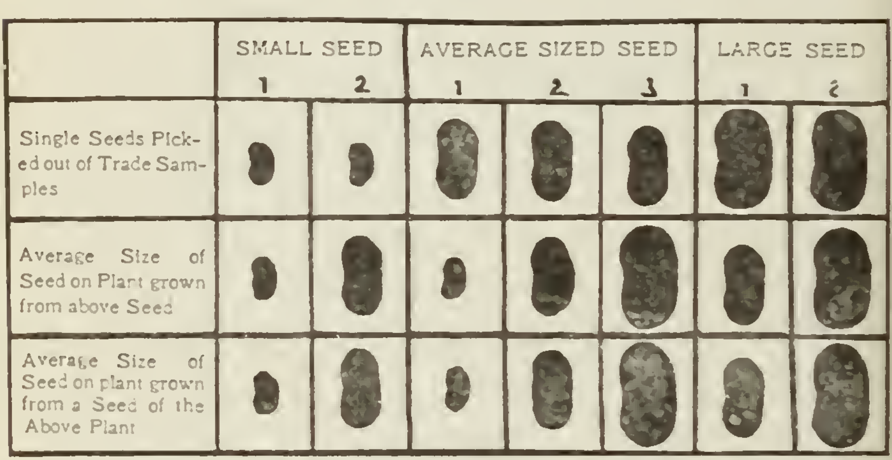

Fig. 14. Diagram to illustrate Johannsen's results with beans (From Wood and Punnett).

2. That a population of beans, no matter from how supposedly "pure" a commercial variety it is taken, is really not a homogeneous unitary aggregation, but instead is made up of a varying number of lines or strains, each of which breeds true to itself when propagated in isolation. In other words, the population in question is a mixture of several component lines. The individuals in each line produce offspring true to the type of the line, rather than to the type of the population as a whole, except in cases where by chance the population type and the type of one or more lines happen to be the same.

3. That when mass selection alters the population type it does so by a process of isolating from the mixture certain strains whose own types are different from the original general popula-

tion type, and which differ in the direction towards which selection was made. Thus if one begins in a general mixed population of beans to select for planting the largest beans, and by so doing increases the average size of the beans in the crop, what he really does is gradually to throw away all beans except those which belong to strains having large beans as the type. Having isolated from the population one of these component strains which breeds true to a definite type no amount of further selection will modify that strain.

The idea underlying these conclusions is that, in the continued propagation of the offspring of any self-fertilized plant, every individual will possess exactly the same hereditary constitution as every other individual. Consequently except for the effect of environmental conditions such a "pure line", as it is called, should breed true and should show the same characters in every generation.

The same reasoning cannot, without some modification, be applied to open fertilized plants, such as corn for example. Here any individual kernel, in the majority of cases, has been fertilized by pollen from some neighboring plant. This latter plant, and consequently its pollen grains, may be carrying characters very different from those of the mother plant. The offspring of such a grain would split up, some showing characters similar to the pollen parent and others like the mother plant. By continued self-fertilization (hand pollination) of corn a condition approaching that of a pure line could be obtained.

The majority of our cereals, such as oats, wheat, barley, etc., are nearly always self-fertilized. Wilson[4] says that natural crossing occurs only very rarely in oats. Rimpau[5] found only five spontaneous crosses in dealing with 19 different varieties during a period of six years. In our own experience we have never observed a single natural cross although in our oat gardens different varieties including black, white and yellow oats, open and side heads, have been grown in adjacent rows. These rows are only one foot apart and at the time of blooming the heads of one row interlock with those of the next. The reason

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[4]Wilson, J. H. The Hybridization of Cereals. Journ. Agric. Sc., Vol. 2. pp. 68-88, 1907.

[5]Rimpau, v. Kreuzungsproduktion Landw. Kulturpflanzen. Landw. Jahr. 1891.

that cross-pollination does not occur is that the anthers shed their pollen before the glumes open, and there is very little chance for the introduction of foreign pollen. Consequently we may assume that for many generations the ancestors of any particular oat plant growing in a field or plot have been self-fertilized and that this plant will breed true to its hereditary characters. This is the fundamental assumption upon which all pure line breeding is based. By the selection and isolation of such pure lines out of ordinary commercial varieties new strains may often be secured which are far superior to the parent variety.

The point in question can perhaps be made still clearer by considering what constitutes a commercial variety. To the casual observer a variety may appear to be breeding perfectly true and all the plants may appear to be alike. However, if the plants are examined carefully many differences will be found. Some have larger heads, or more spikelets per head, others have a larger number of culms, some have stiffer straw than others, etc. Some of these differences are due to environment, such as more space or better ground. On the other hand some of these variations are definitely inherited. If individual plants are selected and the seed of each grown in separate rows, it will be found that many of these rows differ greatly in their yield, time of maturity, strength of straw, etc. These differences are transmitted from one generation to the next. Each plant which breeds differently from the others belongs to a different pure line. A commercial variety then, consists of a mixture of a large number of pure lines which we may designate by the letters

A, B, C, D, E, F, ———— etc.

If we select a single plant it will belong to one of these pure lines, for example *C*. If we multiply the seed of this plant we may have finally a whole field, all the plants of which belong to this pure line *C*.

It further follows from this theory that if we again select individual plants from such a pure line field we have still only the same pure line. If we grow the seed of such selected plants in separate rows there is little or no difference between the rows. That is, in selecting and isolating the pure line we have made all the improvement possible in this direction. Theoreti-

cally and, as Johannsen proved in the case of beans, practically it is not possible to improve such a pure line by further selection.

The question as to whether it is possible to improve a pure line of oats by continued selection has been studied by this Station for several years. The results of three years of such selections have been published.[5] It has been shown that selection for three years both to increase and to decrease certain characters has not modified any of the characters studied.

The results of this work are of much importance to the practical oat breeder. It follows that in order to secure improved strains it is only necessary to select individual plants from the commercial fields and then to multiply the seed of each plant separately. Then each of these pure lines must be tested and only the best retained. After a desirable pure line has been isolated it is only necessary to keep it pure and unmixed with other seed. Such a pure line will not deteriorate nor can it be improved by further selection. This greatly simplifies the methods of practical oat breeding. It has been shown that it is useless to continue the expensive methods of selecting year after year within a pure line. In order to get still better yielding strains it is necessary to go back to commercial fields and make new selections with the hope of isolating still better pure lines. Once a pure line is isolated it cannot be improved by further selection.

Of course, at any time and for reasons at present unknown, germinal variations may occur within a pure line and these may breed true to their new characters. If plants showing such germinal variations should be selected it would be possible to secure strains showing characters different from the parent pure line. While there is good evidence that such germinal variations do occur in oats, they are relatively rare. Practically, there seems to be very little chance of securing such variations from a pure line. (cf. pp. 142-143.)

[5]Surface, F. M. and Pearl, R. Studies on Oat Breeding. II. Selection within pure lines. Maine Agr. Expt. Stat. Ann Rept. 1915, pp. 1-40. (Bulletin No. 235).

Methods.

The general methods of pure line breeding in the case of cereals may be briefly outlined as follows: In the first year individual plants are selected from the fields or plots of the commercial varieties. These plants are selected because in some one or more respects they appear to be better than their neighbors growing under the same conditions. Each of these plants is harvested separately and various data recorded concerning it. On the basis of the notes made in the field and the data on the threshed plants a further selection is made.

The seed from the plants which are finally selected are sown the next spring in short rows in a cereal garden. In our work we usually plant 25 kernels in each row. The rows are one foot apart and the plants three inches apart in the row. This allows each plant sufficient room to develop and the 25 plants are enough to judge the character of each pure line. The garden rows are subjected to a severe selection. Careful notes are taken in the field and considerable data taken at the time of threshing. Out of several hundred rows usually only a few are judged good enough to be continued.

The third year the seed from the selected rows is sown in small multiplying plots. In our work these plots have been 1-2000 acre in area and usually in duplicate. In these plots the grain is planted much closer together in fact, approaching the number of grains per unit area, that are usually sown in the field. These plots are subjected to a still further selection and only the best retained.

The fourth year there is sufficient seed from each selected pure line to sow one or more field plots. According to our method of testing varieties[6] these are sown in 1-40 acre plots. Here they are tested in duplicate or quadruplicate plots for several years and subjected to still further selection until only those which are superior in some respects, at least, to already existing varieties are retained.

In the work with which this bulletin is concerned over 450 plants were selected in 1910. Of these something less than 200 were tested out in garden rows. Eighty were deemed good enough for the 1-2000 acre test, but only 34 ever reached a field

[6]Surface, F. M. and Barber, C. W. Loc. cit.

test. Of these 34 all but 12 have been discarded as not sufficiently valuable to be offered to the public. These 12 pure lines have now been tested for 3 years under field conditions and in competition with the best commercial varieties which we could obtain.

In the following pages some of the details of this work are given and the comparative yields in each year. A description of the 12 pure lines still retained is also given.

This work was begun under the general direction of Dr. Raymond Pearl. The selections in 1910 were all made by the senior writer. In 1911 the work was in charge of Dr. E. P. Humbert. In 1912 Dr. M. R. Curtis and Mr. C. W. Barber looked after the field work. Mr. Barber was also associated with the work in 1913. The present writers were associated in the work of 1914 and 1915 and in the preparation of the data for publication The writers desire to express their appreciation of the careful and efficient assistance rendered throughout this and other work by Mr. Wellington Sinclair, Superintendent of Highmoor Farm.

Work in 1910.

In 1910 25 varieties of oats were tested in 1-10 acre plots at Highmoor Farm. The location of these plots as well as other data concerning them has been given by Surface and Barber.[7]

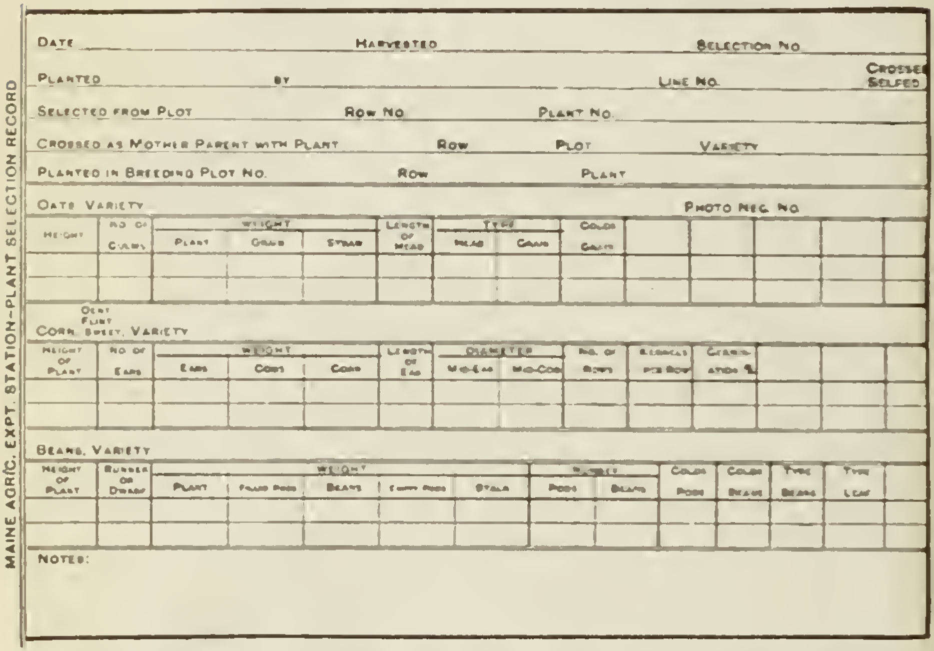
Shortly before harvest a number of these plots were carefully gone over and plants showing points of excellence were given a tag bearing a selection number. The points which were particularly noted in this field selection were the number of culms, the size and general character of the head, the number of spikelets, the number of sterile or abortive spikelets, and the strength of the straw. In making these selections much weight was given to the position of the plant in the plot. Thus usually marginal plants were not chosen because their greater development was manifestly due to better environment. In general, the attempt was made to select plants which were noticeably better in some respects than their neighbors located under the same environmental conditions.

The number on the tag is the plant selection number by which the plant can at any time afterwards be identified in the records. No plant selection number is ever duplicated in the

[7] *Loc. cit.*

plant breeding work of the Station. For those plants which are later multiplied in plots, the plant selection number becomes the "Line Number." Thus when we speak in the latter part of this paper of Line No. 355, it refers us at once to selection number 355 and from this the entire pedigree of the line can be traced. So long as no new germ plasm is added by crossing, the line number remains the same.

Notes were taken at the time of the original selection of each plant. These notes were recorded on 5″ x 8″ loose leaf sheets similar to that shown in facsimile in Figure 15. These sheets,


MAINE AGRIC. EXPT. STATION-PLANT SELECTION RECORD

Date ____ Harvested ____ Selection No ____

Planted ____ by ____ Line No. ____ Crossed / Selfed

Selected from Plot ____ Row No ____ Plant No. ____

Crossed as Mother Parent with Plant ____ Row ____ Plot ____ Variety ____

Planted in Breeding Plot No. ____ Row ____ Plant ____

Oats Variety ____ Photo Neg. No ____

Height	No. of Culms	Weight: Plant	Weight: Grain	Weight: Straw	Length of Head	Type: Head	Type: Grain	Color Grain					

Corn, Dent, Flint, Sweet, Variety ____

Height of Plant	No. of Ears	Weight: Ears	Weight: Cobs	Weight: Corn	Length of Ear	Diameter: Mid-Ear	Diameter: Mid-Cob	No. of Rows	Kernels per Row	Germination %			

Beans, Variety ____

Height of Plant	Runner or Dwarf	Weight: Plant	Weight: Filled Pods	Weight: Beans	Weight: Empty Pods	Weight: Stalk	Pods	Beans	Color Pods	Color Beans	Type Beans	Type Leaf	

Notes:

Fig. 15. Facsimile of plant selection record sheet used in the plant breeding work.

it will be noted, are designed to be used with certain other plants besides oats.

This sheet provides space for data relating to the pedigree of the plant and also such characters of the plant as height, number of culms, weight of grain and straw and certain characters of the head and grain. At the time of the field selection, the date, the name of the variety and the plot from which it came

are recorded. Also brief notes relative to the position of the plant in the plot and the character for which it was especially selected are noted.

When the plants were fully ripened they were pulled and brought into the laboratory. Sometime after they were thoroughly dry they were measured, weighed and threshed.

On the basis of the data thus obtained a further selection of the plants was made. The grain from the best plants was saved for planting in the breeding garden the next year.

In 1910, 460 plants were selected from the variety test plots. These represented 18 different varieties. Of these plants 188 were deemed good enough to be tested in garden rows.

Table 1 shows the plot numbers and the names of the varieties from which plants were selected. Also the number of plants selected from each plot and the number that were grown in the 1911 garden rows.

TABLE I.

Showing the number of plants selected from the different varieties in 1910 and the number of these which were continued in the 1911 oat garden.

1910 plot No.*	VARIETY.	Number selected plants.	Number grown in 1911 garden.
2	Welcome	10	1
3	White Tartar King	11	1
5	Black Tartarian	32	5
6	Kherson	18	3
7	Kherson	6	1
8	Irish Victor	28	14
9	Early Champion	18	9
10	Prosperity	32	14
13	Regenerated Swedish Select	28	12
14	Regenerated Swedish Select	27	20
15	Regenerated Swedish Select	30	6
16	Swedish Select	18	14
17	President	30	18
18	Senator	10	6
19	Victor	14	12
20	Old Island Black	4	1
23	Imported Scotch	21	10
25	Unnamed White	28	14
26	Banner	16	6
27	Banner	16	5
28	Banner	17	1
29	Banner	25	2
31	Hamlin	21	13
	Total	460	188

* For a description of these varieties, source of seed, etc., see Surface and Barber, *Loc. cit.*

Work in 1911.

Seed from the 188 selected plants were grown in garden rows in 1911. In many instances two or more rows were grown from the same plant. Each row was planted with seed from a single culm of the plant. In this way we were certain that all the plants in a given row were the offspring of a single individual. Where plants are taken from a field plot it is not always possible to be certain that several different culms belong to a single plant.

Each row was about 6 feet long and contained 25 kernels. The plants were 3 inches apart in the row and the rows in 1911 were alternately one foot and two feet apart. This brought the rows in pairs with a one-foot space between the rows of a pair and a two-foot space between the pairs of rows. This latter space allowed ample access to the individual plants in taking notes, etc.

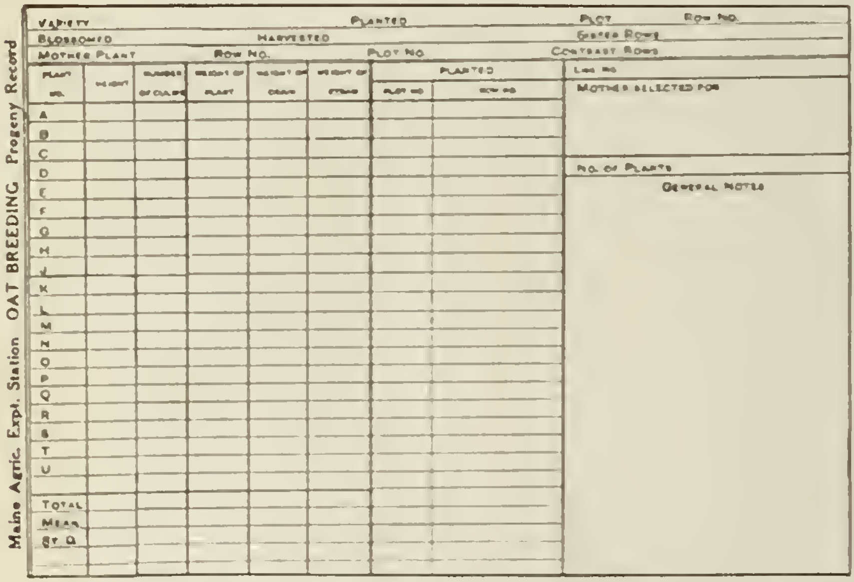


Fig. 17. Facsimile of progeny row record blanks used in the oat breeding work.

Careful notes were taken with regard to each row. When ripe, the plants of each row were pulled and tied together with the row number tag attached. After the plants were thoroughly dry they were weighed, measured and threshed. In some cases each individual plant was threshed separately. In other cases all the plants of a row were threshed together. In either case

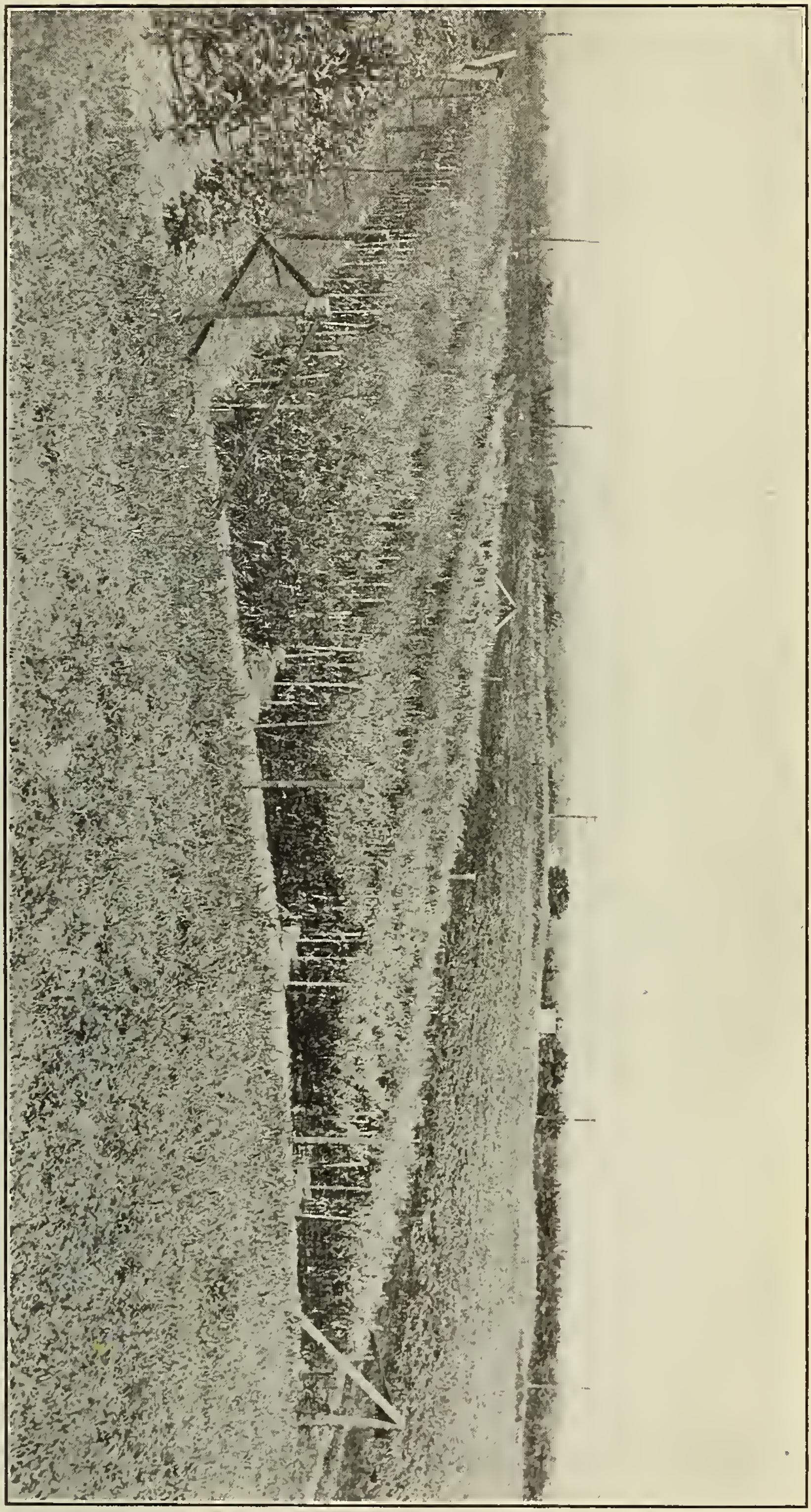


Fig. 16. Photograph of the 1911 oat garden at Highmoor.

all mutilated plants were discarded. The data were recorded on 5″ x 8″ loose leaf sheets like that shown in Fig. 17.

Since the number of threshed plants varied in different rows the average per plant of a given character was used in comparing different rows.

From the notes and the data thus obtained a further selection was made and only the very best rows were selected for propagation the next year.

Work in 1912.

Eighty-two rows from the 1911 garden were regarded as good enough to be tested further. In one case two of these rows belonged to the same pure line. In another case three rows were from the same line. There were then 79 pure lines tested in 1912. Seeds from these selected rows were planted by hand in small plots. These plots were four feet, six inches wide and four feet, ten inches long, giving a total area of 21.75 square feet, or 1-2000 of an acre. The grain was planted in rows three inches apart and one and one-half inches between the plants in the row. There were in each plot 18 rows with 39 plants to the row. This makes 702 plants per plot or at the rate of 1,404,000 plants per acre. This is about the average number of grains of a medium sized oat sown on an acre when seeded at the rate of two bushels. Each pure line was planted in duplicate plots of this size and the average of the two plots for each character was taken for comparison of the different pure lines.

The planting of such plots has been greatly facilitated by the use of a planting board like that shown in figure 18. This board contains rows of 3-8 inch pegs spaced at the proper distances.[9]

During the growing season detailed notes were taken regarding each plot and when ripe the plots were harvested and later threshed. On the basis of these data the pure lines were again subjected to a severe selection. Out of the 79 pure lines tested in these plots 34 were chosen for testing in larger field plots.

The threshing data from these 34 pure lines are given in Table 2. The measurements are recorded in centimeters and

[9]The board shown is designed for marking only half a plot and varies somewhat in shape from that described above.

Fig. 18. Photograph of a planting board used in planting 1-2000 acre plots.

the weights of straw and grain in grams. In order to make these figures more intelligible to those unaccustomed to the metric system, the calculated yield in bushels per acre is also given. It will be understood that in calculating acre yields from small garden plots it is not assumed that in actual practice such yields would necessarily be obtained on the larger areas. However, the translation of yield in grams per 1-2000 acre plot to yield in bushels per acre merely means multiplying the former by a constant factor. So that for purposes of comparing the different pure lines one column can be used as well as the other. As a matter of fact, however, the results obtained in the variety tests in 1914 and 1915 (see tables 4 and 5) indicate that the yields calculated from these garden plots are not far above what may be expected from a properly handled crop in a favorable season.

From Table 2 it is noted that these pure lines averaged to yield at the rate of from 132.8 bushels to 81.3 bushels per acre. It will be understood that the 34 lines given in the table are selected from the 79 which were grown. As a rule the discarded lines yielded less than those given in the table. However, in instances where high yielding lines showed undesirable characters these were also discarded.

TABLE 2.

Data from the 1-2000 acre plots of the 34 selected pure lines. Grown in 1912.

Line No.	PARENT VARIETY.	Height cm.	Weight of straw gms.	Weight of grain gms.	Calculated bushels per acre.
[illegible]47	Imported Scotch	104.1	1871	963.5	132.8
[illegible]6	Irish Victor	113.0	1780	953.5	131.4
346	Irish Victor	108.0	1601	916.0	126.7
281	Banner	115.6	2245	915.0	126.1
74	President	115.6	2317	897.7	123.7
340	Irish Victor	105.4	1[illegible]40	892.5	123.0
250	Imported Scotch	97.7	1520	884.5	121.8
286	Banner	112.5	1999	871.5	120.1
337	Irish Victor	102.9	1569	832.0	114.7
122	Prosperity	104.1	1613	807.0	111.2
82	President	116.8	2280	800.5	110.3
357	Banner	110.8	1901	796.5	109.7
334	Irish Victor	106.7	1602	790.5	108.9
238	Regenerated Swedish Select	101.6	1430	778.0	107.2
199	Prosperity	111.8	1896	775.5	106.9
78	President	100.3	1695	752.0	103.6
351	Banner	110.5	1844	745.5	102.7
355	Banner	104.8	1778	739.8	102.0
198	Prosperity	112.8	1544	737.0	101.6
79	President	111.8	1670	727.0	100.2
307	Banner	106.7	1587	721.5	99.4
230	Banner	105.4	1583	719.5	99.2
[illegible]	Hamlin	100.3	1211	718.0	98.9
7[illegible]	President	109.2	1676	702.5	97.3
128	Regenerated Swedish Select	97.8	1500	701.0	96.5
201	Hamlin	94.0	1238	700.5	96.4
103	President	100.3	1390	697.0	96.0
133	Regenerated Swedish Select	96.5	1152	679.0	93.6
249	Imported Scotch	111.0	1975	656.0	90.4
261	Swedish Select	97.8	1485	630.5	86.9
104	Swedish Select	109.2	1231	619.5	85.9
243	Swedish Select	97.8	1152	606.5	83.6
239	Regenerated Swedish Select	97.8	1398	601.0	82.8
139	Regenerated Swedish Select	96.5	1271	595.0	81.3

It is of interest to note the distribution of these pure lines among the different parent varieties. From Table 1 it is noted that there were 188 pure lines grown in garden rows. These 188 pure lines represent 18 differently named varieties. The 34 lines given in Table 2 represent eight different commercial varieties. It will further be noted from Table 2 that certain

varieties are represented by a large number of lines. These varieties are the Banner, President, Irish Victor and Regenerated Swedish Select. It will further be noted that the majority of the Swedish Select lines are near the bottom of the table, indicating relative low yield.

Work in 1913.

In 1913 each of the 34 lines given in Table 2 were grown in one or more 1-40 acre plots. These plots were located in the field with the plots of the commercial varieties for that year. For a description of the soil, methods of seeding, harvesting, etc., the reader is referred to the earlier paper by Surface and Barber.[9] In each of the three years, 1913 to 1915, in which these pure lines have been tested in field plots, they have been grown in the same field and treated in exactly the same manner as the plots of the commercial varieties. In 1913 the pure line plots were grown all together along one side of the field. In the two other years the pure line plots have alternated with the plots of the commercial varieties.[10]

In 1913 there was not enough seed from many of these lines to plant more than a single plot. Table 3 gives the detailed results for each pure line.

From this table it will be noted that individual plots yielded from 83 to 46 bushels per acre. Four plots yielded above 80 bushels and 10 plots between 70 and 80 bushels per acre. Seven lines with two or more plots gave an average yield of 70 bushels or more.

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[9]Surface, F. M. and Barber, C. W. Studies on Oat Breeding. I. Variety Tests 1910-1913. Maine Agr. Expt. Stat. Ann. Rept. 1914, pp. 137-192. (Bulletin No. 229).

[10]Owing to the fact that the field on which these plots were grown was quite irregular in shape, the method of obtaining corrected yields described on page 114 cannot readily be applied to these plots. For this reason the discussion of the 1913 results is based on the observed yields only.

Table 3.

Test of 34 Pure Lines in 1913.

Variety Number.	Plot number.	Straw Yield. Lbs. per plot.	Straw Yield. Lbs. per acre.	Grain Yield. Lbs. per 1-40 acre plot.	Grain Yield. Observed bu. per acre.	Weight per measured bushel.	Days to maturity.
Maine 336..........	580	93.0	3720	65.0	81.3	35.9	102
	581	70.5	2820	55.5	69.4	38.4	102
Average...........	–	*81.7*	*3270*	*60.3*	*75.3*	*37.2*	*102*
Maine 340..........	578	64.0	2560	52.0	65.0	39.0	99
	*579	100.5	4020	62.5	83.2	36.4	99
Average...........	–	*82.3*	*3290*	*57.3*	*74.1*	*37.7*	*99*
Maine 281..........	565	73.5	2940	53.5	71.2	36.5	105
	601	77.0	3080	60.0	75.0	34.1	105
Average...........	–	*75.3*	*3010*	*56.8*	*73.1*	*35.1*	*105*
Maine 346..........	584	69.0	2760	56.0	70.0	37.4	99
	585	65.0	2600	59.0	73.8	37.3	99
Average...........	–	*67.0*	*2680*	*57.5*	*71.9*	*37.4*	*99*
Maine 78...........	606	71.0	2840	57.0	71.3	39.3	103
Maine 355..........	560	90.0	3600	58.0	72.5	35.6	105
	561	86.0	3440	61.0	76.3	35.5	105
	570	59.5	2380	51.5	64.4	35.8	104
Average...........	–	*78.5*	*3140*	*56.8*	*71.0*	*35.7*	*105*
Maine 286..........	566	79.5	3180	59.5	74.4	35.2	99
	567	68.0	2720	54.0	67.5	–	105
Average...........	–	*73.8*	*2950*	*56.7*	*70.9*	–	102
Maine 357..........	558	93.5	3740	66.5	83.1	36.2	105
	559	87.0	3480	63.0	80.0	35.6	105
	562	56.0	2240	43.0	53.8	36.9	104
	563	62.5	2500	50.5	63.1	36.7	104
Average...........	–	*74.8*	*2990*	*55.7*	*70.0*	*36.4*	*102*
Maine 351..........	564	72.0	2880	56.0	70.0	36.2	105
Maine 128..........	597	75.0	3000	56.0	70.0	37.2	102
Maine 230..........	568	55.7	2228	46.3	69.4	36.7	102
Maine 133..........	602	56.5	2260	46.5	69.3	37.8	101
Maine 217..........	572	63.0	2520	55.0	68.0	37.4	102
Maine 74...........	587	71.5	2860	55.5	69.4	37.9	104
	588	63.5	2540	54.5	68.1	37.8	105
Average...........	–	*67.5*	*2700*	*55.0*	*68.8*	*37.4*	*105*
Maine 243..........	603	64.5	2580	54.5	68.1	37.8	102
Maine 103..........	591	47.7	1908	47.3	67.6	39.5	101
Maine 75...........	586	76.5	3060	54.0	67.5	39.3	104
Maine 239..........	600	64.0	2560	54.0	67.5	39.0	102
Maine 307..........	569	61.5	2460	53.5	66.9	36.8	102
Maine 82...........	589	73.0	2920	55.0	68.8	34.8	106
	590	67.0	2680	51.0	63.8	35.8	106
Average...........	–	*70.0*	*2800*	*53.0*	*66.3*	*35.3*	*106*
Maine 261..........	604	68.0	2720	52.0	65.0	36.9	103
Maine 238..........	598	75.5	3020	54.5	68.1	36.4	103
	599	57.5	2300	46.5	58.1	36.8	102
Average...........	–	*66.5*	*2660*	*50.5*	*63.1*	*36.6*	*103*

* Plots marked with (*) were not exactly 1-40 acre in area when harvested. The yields of these plots have been calculated to a 1-40 acre basis in order to be comparable with the other plots.

TABLE 3.

Test of 34 Pure Lines in 1913—Concluded.

Variety Number.	Plot number.	Straw Yield. Lbs. per plot.	Straw Yield. Lbs. per acre.	Grain Yield. Lbs. per 1-40 acre plot.	Grain Yield. Observed bu. per acre.	Weight per measured bushel.	Days to maturity.
Maine 247	573	72.0	2880	52.0	65.0	37.7	102
	574	101.0	4040	48.5	60.6	35.8	99
Average	–	*86.5*	*3460*	*50.3*	*62.8*	*36.8*	*101*
Maine 201	571	61.0	2440	50.0	62.5	37.2	104
Maine 199	594	62.5	2500	49.5	61.9	36.6	103
Maine 334	583	48.0	1920	48.0	60.0	39.2	95
Maine 139	596	61.0	2440	48.0	60.0	38.5	101
Maine 79	592	66.0	2640	47.0	58.8	36.9	102
Maine 198	593	56.0	2240	47.0	58.8	37.5	103
Maine 337	582	87.2	3488	46.8	58.4	37.5	94
Maine 250	*575	73.2	2928	42.8	55.7	36.4	94
	576	73.5	2940	38.5	48.1	36.8	94
Average	–	*73.4*	*2934*	*40.7*	*51.9*	*36.6*	*94*
Maine 122	595	77.5	3100	41.5	51.9	36.3	101
Maine 249	577	48.5	1940	34.5	50.8	36.8	94
Maine 104	605	63.0	2520	34.0	46.0	43.7	89
Average for all lines	–	*67.7*	*2709*	*50.9*	*65.0*	*37.4*	*101*

* Plots marked with (*) were not exactly 1-40 acre in area when harvested. The yields of these plots have been calculated to a 1-40 acre basis in order to be comparable with the other plots.

The average yields of the commercial varieties tested in 1913 have been given by Surface and Barber (*loc. cit.*). By reference to Table 6 of that paper it will be noted that only one variety, the Siberian, yielded as high as 70 bushels.

The fact that the plots of the commercial varieties and the pure lines were arranged on separate sides of the field in 1913 make it somewhat difficult to draw reliable comparisons. As a whole, the land on which the pure lines were grown was somewhat inferior to that on which the commercial varieties grew. Nevertheless, individual lines far outyielded the commercial varieties. The average yields of the two sets of plots did not show a very great difference. The 21 commercial varieties averaged to yield 62 bushels per acre, while the 34 pure lines gave 65 bushels.

Work in 1914.

In 1914, 31 of these pure lines were tested again. Three lines, viz., 139, 243 and 249, were discarded because they possessed certain undesirable characters. The data from the 1913 test were not sufficient to warrant discarding any of the other lines. By this time practically all of the lines possessing weak straw, poor head character, or poor grain had been discarded. The further selection in these pure lines would have to be largely upon the question of yield. Consequently two or three years records are necessary.

Owing to a large amount of other work in 1914, it was not possible to plant more than two plots of each pure line. Two lines were represented by only a single plot. These pure line plots alternated in the field with the plots of standard commercial varieties. They were therefore tested under exactly the same conditions so far as that was possible.

In connection with these tests a method has been devised to correct the yields of individual plots for differences in the soil. Before discussing the results of the 1914 tests it will be necessary to consider this method very briefly.

The method used by us in testing varieties is to grow several (usually 4) systematically repeated plots of the same variety. These plots are each 33 feet square, or 1-40 of an acre. Where four of these are grown it makes 1-10 acre devoted to each variety. It has been clearly proven that much more satisfactory results are obtained by growing several systematically repeated small plots of one variety than by growing a single large plot. With single plots one of these may fall on better ground and give a much better yield for that reason, although the intrinsic yielding ability of the variety may not be as good as some of the others which were on poorer soil. Where several plots are grown and scattered over the field there is much less chance of all of them falling in very good or very poor soil.

Even where several plots are grown there is some chance that one or two of these will fall in exceptionally good or exceptionally poor soil and these may unduly affect the average yield. To take account of this, a method has been devised by which the yield of each plot can be corrected for differences in

soil. The details of this method have been published[11] in another place and will not be repeated here. Briefly the principle upon which this method is based is to determine first the most probable yield of each plot in the field on the assumption that there is no intrinsic difference in the yield of the different varieties. In other words, a "calculated" yield is obtained which is the probable yield of each plot on the assumption that all plots had been planted with a hypothetical variety whose mean yield is the same as the observed average of all the plots.

The differences between the "calculated" yield of any plot and the average of the field may be taken as a measure of the goodness of the soil in that plot. Thus if a certain plot has a "calculated" yield of 10 bushels above the average of the field, it means that the soil on this plot is capable of producing about 10 bushels per acre more grain than the field as a whole. Therefore, the observed yield of the variety on this plot is higher than it ought to have been for comparative purposes. In order to make the yield of this plot comparable with the field as a whole it would be necessary to deduct 10 bushels (or at least a percentage figure based on this amount) from the observed yield. In case the "calculated" yield is below the average of the field a corresponding amount must be added to the observed yield. For further details of this method with examples the reader is referred to the above mentioned paper.

This method has been tested out under a variety of conditions and appears to give very satisfactory results. We have applied this method of correction to the 1914 and 1915 plots and the discussion of the results will for the most part be based on these corrected yields. The 1913 plots were on a somewhat irregularly shaped piece of ground and it was not possible to use this method of correction satisfactorily.

There is no doubt but that small plots of oats like these give a somewhat higher absolute yield than can be expected when an entire field is planted. The reason for this is that the necessary pathways allow more air and sunlight and also afford more plant food for the marginal plants. However this may be, there is positive evidence that much better results are

[11]Surface, F. M. and Pearl, R. On a Method of Correcting for Soil Heterogeneity in Variety Tests. Jour. Agric. Research, Vol. V, pp. 1039 to 1050, 1916.

obtained in a variety test with several small plots of each variety than with a single large one. Furthermore all the plots are subjected to the same conditions and consequently the results are comparable. Some of our observations indicate that the yield of oats in 1-40 acre plots may be 10 per cent higher than in a large field. If the reader so desires he may reduce the yield reported, by 10 or even 15 per cent but that will not in the least affect the conclusions drawn from this work as to the *relative* value of these varieties. It is this relative value which we are trying to determine. The use of systematically repeated small plots helps very materially in reducing the experimental errors due to differences in soils and other environmental conditions and aids us in determining the relative intrinsic value of the different varieties.

In 1914 the test plots were located in the field to the southwest of the buildings on Highmoor Farm. They were on the west side of the farm road and extended from the house almost to Ben Davis No. 1 orchard. This field had been in potatoes in 1913. The land was apparently very uniform with the exception of a few places where a ledge came near the surface. These spots were not included in the variety test. The methods of handling the soil and the crop were the same as those given in a previous paper.[12]

The plots were arranged in six tiers, each with 28 plots. Allowing for plots not planted on account of ledges, etc., there were 148 plots in the variety test. Eighty-eight of these were sown with commercial varieties, i. e., there were 22 commercial varieties with four plots each. The remaining plots contained the pure line varieties discussed in this paper. The plots were planted May 3 to 6 with the exception of a few which on account of heavy rains could not be sown until about ten days later.

The seasonal conditions for oats in 1914 were very favorable. A sufficient supply of moisture well distributed throughout the season produced a very heavy crop. The yield in this year was much heavier than can be expected throughout a series of years.

The yield and other data for each of the pure line plots together with the average observed and corrected yield of each line is given in Table 4.

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[12]Surface and Barber. *Loc. cit.*

Table 4.

Test or Pure Lines in 1914.

Variety Number.	Plot number.	Straw. Lbs. per 1-40 a. plot.	Straw. Lbs. per acre.	Grain. Lbs. per 1-40 a. plot.	Grain. Observed Yield. Bus. per acre.	Corrected yield. Bushels per acre.	Weight per measured bushel.	Days to maturity.
Maine 355	685	110.0	4400	79.0	98.7	116.0	37.1	97
	760	73.3	2932	69.3	86.6	94.6	39.0	96
Average	-	*91.7*	*3666*	*74.2*	*92.7*	*105.3*	*38.1*	*97*
Maine 337	712	137.7	5308	96.3	120.3	103.9	42.3	99
Maine 351	687	102.0	4080	79.0	98.8	93.3	40.3	104
	762	104.8	4192	81.3	101.6	103.1	39.4	93
Average	-	*103.4*	*4136*	*80.1*	*100.2*	*98.2*	*39.9*	*98*
Maine 201	698	106.0	4240	82.0	102.5	105.9	-	100
	773	87.3	3492	68.8	85.9	88.5	-	92
Average	-	*96.7*	*3967*	*75.4*	*94.2*	*97.2*	-	*96*
Maine 281	690	91.5	3660	74.5	93.1	93.7	41.6	102
	765	88.3	3532	74.8	93.4	99.5	39.7	94
Average	-	*89.9*	*3596*	*74.7*	*93.3*	*97.0*	*40.7*	*98*
Maine 122	736	97.3	3892	76.8	95.9	95.8	-	92
	810	93.5	3740	75.5	94.4	97.1	-	92
Average	-	*95.4*	*3816*	*75.7*	*95.2*	*96.4*	-	*92*
Maine 307	696	110.0	4400	76.0	95.0	97.8	38.1	98
	771	96.0	3840	77.5	96.9	93.8	38.1	99
Average	-	*103.0*	*4120*	*76.8*	*96.0*	*95.8*	*38.1*	*99*
Maine 340	707	121.3	4852	88.0	110.0	95.7	41.9	97
	781	117.5	4700	86.0	107.5	95.9	41.6	91
Average	-	*119.4*	*4776*	*87.0*	*108.8*	*95.8*	*41.8*	*94*
Maine 217	701	84.8	3392	68.8	85.9	99.8	-	98
	776	90.5	3620	71.5	89.4	90.0	-	99
Average	-	*87.7*	*3506*	*70.2*	*87.7*	*94.9*	-	*99*
Maine 230	694	77.0	3080	80.0	100.0	101.5	40.3	104
	769	122.8	4892	86.0	108.4	86.0	38.7	96
Average	-	*99.9*	*3986*	*83.0*	*104.2*	*93.8*	*39.5*	*100*
Maine 261	747	105.3	4212	78.5	98.1	93.5	39.4	93
	821	97.2	3888	74.8	93.7	92.9	39.7	92
Average	-	*101.3*	*4050*	*76.7*	*95.9*	*93.2*	*39.6*	*93*
Maine 238	740	68.5	2740	60.5	75.6	87.6	-	93
	814	100.8	4032	79.3	99.1	98.6	-	91
Average	-	*84.7*	*3386*	*69.9*	*87.4*	*93.1*	-	*92*
Maine 247	703	103.5	4140	83.5	104.4	98.0	39.8	100
	778	122.5	4900	82.5	103.1	86.8	40.2	91
Average	-	*113.0*	*4520*	*83.0*	*103.8*	*92.4*	*40.0*	*96*
Maine 128	738	104.3	4172	68.8	85.9	87.2	44.2	104
	812	95.0	3800	74.5	93.1	95.1	41.3	92
Average	-	*99.7*	*3986*	*71.7*	*89.5*	*91.2*	*42.8*	*98*
Maine 334	715	112.8	4512	80.3	100.3	86.7	41.1	100
	788	98.0	3920	78.0	97.5	94.3	38.4	89
Average	-	*105.4*	*4216*	*74.2*	*98.9*	*90.5*	*39.7*	*94*
Maine 346	720	107.5	4300	84.2	105.3	103.2	41.0	100
	794	99.3	3972	60.8	75.9	75.8	40.3	99
Average	-	*103.4*	*4136*	*72.5*	*90.6*	*89.5*	*40.7*	*100*

TABLE 4.

Test or Pure Lines in 1914—Concluded.

Variety Number.	Plot number.	Straw. Lbs. per 1-40 a. plot.	Straw. Lbs. per acre.	Grain. Lbs. per 1-40 a. plot.	Grain. Observed yield. Bus. per acre.	Corrected yield. Bushels per acre.	Weight per measured bushel.	Days to maturity.
Maine 336	709	113.0	4520	86.5	108.1	86.2	40.6	100
	783	92.8	3712	76.3	95.3	92.2	40.5	96
Average	–	*102.9*	*4116*	*81.4*	*101.7*	*89.2*	*40.5*	*98*
Maine 79	730	95.8	3832	73.3	91.6	82.0	–	102
	804	112.0	4480	78.5	98.1	95.0	–	95
Average	–	*103.9*	*4156*	*75.9*	*94.9*	*88.5*	–	*99*
Maine 82	726	102.5	4090	80.5	100.6	94.7	–	105
	800	107.3	4292	65.8	82.2	81.4	–	99
Average	–	*104.9*	*4191*	*73.2*	*91.4*	*88.1*	–	*103*
Maine 75	722	56.0	2240	54.0	67.5	81.0	39.7	95
	796	116.8	4662	78.3	97.8	93.5	39.7	93
Average	–	*86.4*	*3451*	*66.2*	*82.7*	*87.3*	*39.7*	*94*
Maine 286	692	165.5	6620	80.0	100.0	102.1	36.5	95
	767	91.2	3648	74.8	93.4	72.2	37.4	92
Average	–	*128.4*	*5134*	*77.4*	*96.7*	*87.1*	*37.0*	*94*
Maine 250	705	53.0	2220	59.0	73.7	86.8	–	93
Maine 198	732	122.3	4892	75.8	94.7	86.5	–	104
	806	112.0	4480	71.0	88.8	85.3	–	98
Average	–	*117.2*	*4686*	*73.4*	*91.8*	*85.9*	–	*101*
Maine 199	734	80.3	3212	62.8	78.4	84.0	–	97
	808	112.0	4480	71.0	88.8	87.7	–	98
Average	–	*96.2*	*3846*	*66.9*	*83.6*	*85.8*	–	*98*
Maine 103	728	64.8	2592	61.3	76.6	83.9	–	93
	802	105.5	4220	74.5	93.1	86.1	–	95
Average	–	*85.2*	*3406*	*67.9*	*84.9*	*85.0*	–	*94*
Maine 74	724	95.8	3832	69.3	86.6	80.0	–	99
	798	91.8	3672	70.3	87.8	87.6	–	91
Average	–	*93.8*	*3752*	*74.8*	*87.2*	*83.8*	–	*95*
Maine 357	683	87.5	3500	67.0	87.7	82.2	38.4	111
	758	88.3	3532	60.3	75.3	83.9	38.7	99
Average	–	*87.9*	*3516*	*63.7*	*81.5*	*83.1*	*38.6*	*105*
Maine 133	745	75.3	3012	68.8	85.9	85.5	–	93
	819	93.0	3720	56.8	70.9	78.4	–	98
Average	–	*84.2*	*3366*	*62.8*	*78.4*	*82.0*	–	*96*
Maine 78	753	70.5	2820	55.0	68.8	82.7	–	99
	827	84.0	3360	54.0	69.0	72.8	–	98
Average	–	*77.3*	*3090*	*54.5*	*68.9*	*77.8*	–	*99*
Maine 239	743	78.8	3152	61.3	80.2	81.7	–	99
	817	103.0	4120	55.0	68.8	71.4	–	98
Average	–	*90.9*	*3636*	*58.2*	*74.5*	*76.6*	–	*99*
Maine 104	751	82.0	3280	49.0	61.2	67.0	–	91
	825	81.0	3240	49.0	61.2	64.4	–	88
Average	–	*81.5*	*3220*	*49.0*	*61.2*	*65.7*	–	*90*
Average of all lines	–	97.6	3902	72.4	90.7	86.9	39.9	97

From this table (4) it will be noted first that the yields of grain are absolutely much higher than in 1913. Individual plots gave an observed yield as high as 120 bushels per acre. The reason for this is partly in the better soil in the 1914 field, but more especially in the very favorable season. While there was abundant moisture well distributed throughout the growing season, nevertheless there were no flooding rains or heavy wind storms to damage the crops. As a matter of fact, the seasonal conditions were almost ideal. The yields obtained in 1914 would seem to represent almost a maximum production.

The average observed yield for the several pure lines ranged from 108.8 bushels in No. 340 to 62.2 bushels in No. 104. Thus showing a range of over 46 bushels between the highest and the lowest yielding lines.

The corrected average yield per acre varied from 105.3 bushels in No. 355 to 65.7 bushels in No. 104. The range is about 6 bushels less than in the case of the observed yields.

The average corrected yield of all the pure lines tested was 86.9 bushels. This is nearly 22 bushels per acre better than the average of these pure lines in 1913.

The highest observed yield among the 22 commercial varieties tested in 1914 was 105 bushels for the Minnesota 26. This was the only commercial variety with an observed yield of over 100 bushels. On the other hand, six of the pure line varieties gave an average observed yield of over 100 bushels. Regarding the corrected yields, which is undoubtedly a fairer basis of comparing the varieties, the highest yield in a commercial variety was 96.1 bushels shown by the Lincoln variety. There were six pure lines which gave an average corrected yield of over 96 bushels. More detailed comparison of the yield of commercial varieties and pure lines will be given after the results of the 1915 test have been considered.

The average yield of straw per acre varied from 5308 pounds to 3090 with an average of 3902 pounds. Comparing this with the average weight of straw in 1913 (Table 3) it is seen that the straw yield in 1914 is nearly 1200 pounds per acre greater than in the preceding year.

The weight per measured bushel was not obtained for all of the lines. For the sixteen lines in which it was determined the

average weight varied from 42.8 to 37.0 pounds per bushel with an average of 39.9. Comparing with Table 3, it will be seen that this average is over two pounds per bushel higher than in 1913, showing that the increased yield was accompanied by an increase in quality.

The number of days from planting to harvesting varied from 105 to 90 with an average of 97. This was an average of four days less than in 1913.

Work in 1915.

In order to test more thoroughly some of these pure lines a number of the poorer ones were discarded entirely as showing nothing essentially better than already found in commercial varieties. Certain other of these pure lines were held over to be tested more thoroughly in later years. Twelve of these lines were grown in quadruplicate plots in 1915 in connection with 11 of the best commercial varieties. The pure line plots alternated with the plots of the commercial varieties. A map of these 1915 plots has been published in connection with another paper[13].

These 1915 plots were located on the east side of the farm road leading from the buildings on Highmoor Farm to Ben Davis No. 1 orchard. They were on the end of the field next to the orchard. This land had been in grass in 1913. This field had been cropped for several years and was somewhat deficient in humus. It was plowed in the fall of 1913 and in 1914 a crop of buckwheat was grown and turned under.

The method of preparing the land, fertilizing, planting, etc., were the same as in previous years. The plots were planted on April 21 and 22, about 10 days earlier than usual at Highmoor.

The detailed results of the 1915 test of the 12 pure lines are given in Table 5. The lines are arranged in the order of their corrected yield.

From this table it is noted first that the yields, both observed and corrected, are somewhat lower than in 1914, but distinctly higher than in 1913. The season of 1915 was in many respects favorable for oats. In particular there was abundant moisture

[13]Surface, F. M. and Pearl, R. On a Method of Correcting for Heterogeneity in Variety Tests. Journ. Agr. Research, Vol. V., pp. 1039-1050, 1916.

throughout the growing season and the early part of the season was cool. Both of these things are essential to a good oat crop. The chief disturbing factor was the very heavy flooding rains often accompanied by wind. Any varieties which had a tendency to lodge were very severely affected. As a matter of fact, these varieties had all been carefully selected with reference to strength of straw and few of them lodged to any extent. Further mention will be made of this in a later paragraph.

TABLE 5.

Test of Pure Lines in 1915.

Variety.	Plot number.	Straw Yield.		Grain Yield.			Weight per measured bushel.	Days to maturity.
		Lbs. per plot.	Lbs. per acre.	Lbs. per 1-40 acre plot.	Observed. Bushels per acre.	Corrected.		
Maine 340	908	80.8	3232	66.2	82.8	82.6	39.7	114
	933	96.3	3852	67.2	84	84.1	39.4	117
	958	94.5	3780	60.3	75.3	75.6	38.4	119
	983	93.8	3752	71.2	89	91.9	40.3	112
Average	-	*91.4*	*3654*	*66.2*	*82.8*	*83.6*	*39.4*	*116*
Maine 355	915	87.8	3512	59	73.8	78.6	35.5	119
	940	106.7	4268	74.5	93.1	82.8	36.2	117
	965	98.5	3940	62.5	78.1	83.7	37.8	119
	990	101.7	4068	67	83.8	89.1	37.1	118
Average	-	*98.7*	*3947*	*65.8*	*82.2*	*83.6*	*36.6*	*119*
Maine 281	911	100.8	4032	66.7	83.4	81.4	39.0	116
	936	80.5	3220	55	68.8	71	35.8	119
	961	96	3840	65	81.3	82.9	35.8	118
	986	95	3800	73.5	91.9	89.4	37.8	117
Average	-	*93.8*	*3723*	*65.1*	*81.4*	*81.2*	*37.1*	*118*
Maine 337	906	91.5	3660	71	88.8	79.4	37.8	114
	931	82.7	3308	65	81.3	87.8	39.0	117
	956	71.5	2860	59	73.8	74.5	37.8	115
	981	80.3	3212	57.3	71.6	75	37.4	118
Average	-	*81.5*	*3260*	*63.8*	*78.9*	*79.2*	*38.0*	*116*
Maine 247	913	84.5	3380	67.5	84.4	85.2	38.4	114
	938	95.5	3820	72.5	90.6	70.2	37.1	113
	963	69.7	2788	56	70	80.1	37.1	118
	988	82.5	3300	60.5	75.6	80.8	38.4	113
Average	-	*83.1*	*3322*	*64.1*	*80.2*	*79.1*	*37.8*	*115*
Maine 357	898	100.3	4012	68.8	85.9	85.2	35.5	123
	923	79.2	3168	59	73.8	78.9	34.6	119
	948	93.8	3752	65.7	82.1	80.7	35.8	118
	973	94.2	3768	61.5	76.9	71.7	36.2	118
Average	-	*91.9*	*3675*	*63.8*	*79.7*	*79.1*	*35.5*	*120*
Maine 230	902	99.9	3996	60.2	75.3	76.4	38.4	123
	927	94.8	3792	59.7	74.6	72.6	37.8	119
	952	90.5	3620	61	76.3	76.9	36.5	119
	977	86	3440	68.5	85.6	81.4	37.1	115
Average	-	*92.8*	*3712*	*62.4*	*78.6*	*76.8*	*37.4*	*118*

TABLE 5.

Test of Pure Lines in 1915—Concluded.

Variety.	Plot number.	Straw Yield. Lbs. per plot.	Straw Yield. Lbs. per acre.	Grain Yield. Lbs. per 1-40 acre plot.	Grain Yield. Observed. Bushels per acre.	Grain Yield. Corrected.	Weight per measured bushel.	Days to maturity.
Maine 346	919	95	3800	55.5	69.4	67.1	38.7	119
	944	77	3080	66	82.5	75.7	35.2	111
	969	71.5	2860	61.5	76.9	83.6	37.1	112
	994	90	3600	72.	90.	81.7	39.0	112
Average	–	*83.4*	*3335*	*63.8*	*79.7*	*77.0*	*37.5*	*114*
Maine 307	917	97.5	3900	61.5	76.9	75.7	36.5	119
	942	99.8	3992	65.7	82.1	72.6	36.5	117
	967	94.0	3760	62.	77.5	81.8	36.8	119
	992	78.0	3120	57.	71.3	77.9	36.5	113
Average	–	*92.3*	*3693*	*61.6*	*77.0*	*77.0*	*36.6*	*117*
Maine 286	921	94.	3760	68.5	85.6	85.8	38.4	117
	946	89.5	3580	68.5	85.6	75.1	37.1	112
	971	85.8	3432	62.3	77.8	79.2	37.8	119
	996	95.2	3808	49.5	61.9	62.5	37.8	117
Average	–	*91.1*	*3645*	*62.2*	*77.7*	*75.7*	*37.8*	*116*
Maine 351	900	101.8	4072	62.2	77.8	79.3	36.5	119
	925	96.8	3872	62.7	78.4	77.6	38.1	118
	950	93.	3720	58.5	73.1	71.4	38.4	117
	975	102.5	4100	64.5	80.6	73.8	38.4	118
Average	–	*98.5*	*3941*	*62.0*	*77.5*	*75.5*	*37.8*	*118*
Maine 336	904	80.	3200	59.	73.8	77.1	39.0	114
	929	91.5	3660	57.8	72.2	72.7	39.4	119
	954	89.8	3592	67.3	84.1	76.3	37.8	117
	979	93.5	3740	52.8	65.9	74.1	37.8	119
Average	–	*88.7*	*3548*	*59.2*	*74.3*	*75.1*	*38.5*	*117*
Average of all lines	–	*90.6*	*3622*	*61.7*	*79.1*	*78.6*	*37.5*	*116*

It will be noted from this table that the observed and corrected yields are very nearly parallel in the majority of these pure lines. The reason for this is that the soil in the 1915 field was much more uniform than that used in the preceding year. The following discussion unless specifically stated will be based on the corrected yield.

The corrected yield of individual plots ranged from 91.9 to 62.5 bushels. The highest average yield was for No. 340 and No. 355, viz., 83.6 bushels each. The lowest average yield was 75.1 bushels in Line No. 336. The average yield of all the lines was 78.6 bushels per acre. This was about 8 bushels per acre less than in 1914.

The average yield of straw per acre was 3622 pounds or nearly 300 pounds less than in 1914.

The average weight per measured bushel was 37.5 pounds, or 2.4 pounds less than in 1914.

The most marked variation was in the Days to Maturity. For individual plots this ranged from 123 to 112 with an average of 116. This was 19 days more than in 1914 and 15 days more than in 1913. The reason for this probably lies in the nature of the season and also in the fact that the plots were sown very much earlier than in former years. Apparently the grain ripened at about the same time of the year as usual regardless of the fact that it had been planted 10 to 12 days earlier.

More detailed discussion of these pure lines will be undertaken in later paragraphs.

VARIATION IN THE YIELD OF THE 1915 PLOTS.

Surface and Barber (*Loc. cit.*) have pointed out that other things being equal the variety which shows the least tendency to vary under different environmental conditions is the best variety. Thus what is most desired in a variety is one which will give a good substantial yield under all kinds of soil and climatic conditions to which it is likely to be subject. Only in 1915 are there sufficient data for determining the variation between different plots. For this purpose it is desirable to use the observed yields instead of the corrected. In the case of the corrected yields other factors enter which, on the whole, tend to lower the variability. The variation in the *observed* yield shows the actual amount of difference due to differences in soil and other environmental conditions.

TABLE 6.

Constants of Variation in Yield for the Four 1915 Plots of Each Pure Line. Observed Yields.

VARIETY.	Mean.	Standard deviation	Coefficient of variation.
Maine 351	77.47 ± .91	2.73 ± .65	3.52 ± .84
Maine 307	76.94 ± 1.30	3.86 ± .92	5.02 ± 1.20
Maine 230	77.94 ± 1.50	4.47 ± 1.06	5.73 ± 1.37
Maine 357	79.67 ± 1.58	4.70 ± 1.12	5.90 ± 1.41
Maine 340	82.77 ± 1.65	4.90 ± 1.16	5.92 ± 1.41
Maine 337	78.83 ± 2.27	6.76 ± 1.61	8.58 ± 2.06
Maine 336	73.99 ± 2.19	6.51 ± 1.55	8.79 ± 2.11
Maine 355	82.19 ± 2.44	7.24 ± 1.72	8.81 ± 2.11
Maine 346	79.69 ± 2.54	7.56 ± 1.80	9.49 ± 2.28
Maine 247	80.15 ± 2.66	7.92 ± 1.88	9.88 ± 2.16
Maine 281	81.31 ± 2.78	8.27 ± 1.97	10.17 ± 2.45
Maine 286	77.73 ± 3.26	9.69 ± 2.31	12.47 ± 3.01
Average	79.06	6.22	7.86

Table 6 shows the variation constants[14] for the 1915 plots based upon the observed yields. The varieties are arranged in the order of their coefficients of variation.

The following points may be noted from this table:

1. The standard deviation ranges from 2.73 bushels per acre to 9.69 bushels. This is a somewhat smaller range than has usually been observed for a similar number of commercial varieties.

2. The coefficient of variation is to be regarded as the better measure of variability in cases like this. This constant varies from 3.52 per cent to 12.47 per cent with an average of 7.86.

3. With regard to the coefficient of variation, the table falls into two parts. The first five varieties have a coefficient of less than 6 per cent and may be regarded as showing a low degree of variability. The remaining lines have a coefficient of from 8.5 to 12.5 per cent and thus have a medium variability. Two of the higher yielding lines, viz., 340 and 357, are included in the first part of the table. Insofar as the evidence goes these varieties are to be regarded as more desirable than those with an equal yield, but greater variability.

Too much reliance should not be placed upon these constants which are derived from a relatively small number of plots and for one year only. They may, however, serve to help point out the desirability of certain lines which for other reasons are believed to excell in quality.

Mean Production for the Three Years.

The 12 pure lines grown in 1915 have now been tested for three years. While the tests have not included the same number of plots each year, the number of plots and other conditions were nearly the same for each line in each year. Therefore, the yields in individual years ought to afford some expression of the *relative* merits of the different lines under the conditions of that year. Although the data are not all that could be desired, some information can be obtained by averag-

[14]The meaning and the method of determining these constants and their probable errors has been given by Surface and Barber (*Loc. cit.*)

ing the results of the three years. The most important character is of course the yield of grain. This will be considered first.

In the years 1914 and 1915 we have based the discussion mainly on the corrected yields. For reasons discussed above it is not practicable to apply the correction method to the 1913 plots. In the tables below we have used the observed yield for 1913 and the corrected yield for the other two years. This method is perfectly justifiable and after careful consideration has seemed to be the best method of dealing with these data. While some of the 1913 yields are admittedly influenced by heterogeneity in the soil, this does not seem to offer any sound reason for introducing similar errors in the later years.

Table 7 gives the 12 pure lines arranged in the order of their average yield. The yield for each of the three years is given together with the three-year average. In addition to this the name of the parent variety from which the selection was made is also given.

TABLE 7.

Yield of Grain. Pure Lines Tested for Three Years.

Line number.	Parent Variety.	Bushels per Acre.			
		1913.	1914.	1915.	Mean.
Maine 355	Banner	71.0	105.3	83.6	86.6
340	Irish Victor	74.1	95.8	83.6	84.5
281	Banner	73.1	97.0	81.2	83.8
351	Banner	70.0	98.2	75.5	81.2
337	Irish Victor	58.4	103.9	79.2	80.5
230	Banner	69.4	93.8	76.8	80.0
307	Banner	66.9	95.8	77.0	79.9
336	Irish Victor	75.3	89.2	75.1	79.9
346	Irish Victor	71.9	89.5	77.0	79.5
247	Imported Scotch	62.8	92.4	79.1	78.1
286	Banner	70.9	87.1	75.7	77.9
357	Banner	70.0	83.1	79.1	77.4
	Average	69.5	94.4	78.6	80.8

One of the most striking things about this table is the preponderance of certain parent varieties. These pure lines were selected from the 188 lines grown in the 1911 garden solely on their merits, without thought or often even without knowledge of the parent variety. Fourteen of the 188 1911 rows were from the Banner variety (cf. Table 1). Seven of these are included in the above table. Likewise there were 14 Irish Victor rows in 1911 and 4 of these have been continued. Only one

other variety out of the original 18 is represented in the final selection. This is the Imported Scotch with a single line. Evidently either the Banner and Irish Victor possessed better yielding ability or else these varieties tend to throw desirable inheritable variations more frequently than the others. These points will be referred to below.

The average yield of these pure lines ranged from 86.6 bushels to 77.4. A total range of about 9 bushels. The average of the twelve lines for the three years is about 81 bushels per acre.

The highest yielding line is No. 355. Nos. 340 and 281 were only slightly below the former.

The next six lines, Nos. 351, 337, 230, 307, 336, and 346, give an average yield of approximately 80 bushels per acre. The three remaining lines are probably to be regarded as slightly inferior in yielding ability, although a consideration of the yields in individual years does not always indicate this.

On the whole these results indicate that these pure lines are remarkably uniform in yielding ability. While there are some differences in their relative yield from year to year and in the average yield, nevertheless they are all well adapted to the conditions under which they are grown at Highmoor. This is, of course, what might be expected from the fact that these are what remain after discarding the poorer strains from 460 original selections.

It is now of interest to compare the yield of these pure lines with the yield of the best obtainable commercial varieties grown in the same years and under exactly the same conditions as nearly as this is possible. There are 11 commercial varieties which have been tested for all three years. For the most part these represent the best commercial varieties which we have been able to obtain. They are selected from over 40 varieties that have been tested at Highmoor. Two or three of these varieties are retained because they represent distinct types of oats or like the Swedish Select because they are very popular in this State.

Table 8 gives the yields for these 11 commercial varieties. In order to make the tables as comparable as possible the observed, uncorrected, yield is given for 1913 and the corrected yields for 1914 and 1915.

TABLE 8.

Yield of Grain, Commercial Varieties.

Variety.	Bushels per Acre.			
	1913.	1914.	1915.	Mean.
Early Pearl	69.7	93.9	82.3	82.0
Minnesota 26	67.7	94.4	82.7	81.6
Banner	62.7	94.5	81.8	79.7
Gold Rain	65.2	90.3	77.9	77.8
Siberian	71.1	83.3	77.1	77.2
Prosperity	63.0	92.1	74.1	76.4
Irish Victory	67.0	82.4	76.2	75.2
Imported Scotch	67.7	87.1	64.8	73.2
Kherson	60.8	82.7	66.8	70.1
Swedish Select	60.9	79.9	68.3	69.7
Senator	51.7	83.6	57.9	64.4
Average	64.3	85.8	73.6	75.2

From this table and the preceding it is noted:

(1) That the average yield ranges from 82 bushels for the Early Pearl to 64.4 bushels for the Senator. This is a range of over 17 bushels or very nearly twice as much as for the 12 pure lines.

(2) The average yield is 75.2 bushels against 80.8 for the pure lines.

(3) The highest yield of the varieties is 82 bushels while three of the pure lines exceed this figure. The highest yield in the pure lines is 86.6 bushels.

(4) Only four of the 11 commercial varieties give a better yield than the *poorest* of the pure lines.

(5) The seven Banner pure lines average to yield 81 bushels per acre while the parent variety in the same years gave 79.7 bushels. This is an average increase of a little less than a bushel and a half per acre. Of course some individual lines far exceeded this.

(6) The four Irish Victor pure lines averaged to yield 81.1 bushels while the parent variety gave only 75.2 bushels an increase in the pure lines of nearly 6 bushels per acre.

While these differences may appear insignificant to some readers, such is not the case. These varieties and pure lines have been tested under conditions which are as nearly uniform for all plots as it is possible to make them. Corrections have been applied which take account of differences in the fertility of the soil of different plots. Checks upon the accuracy of the work have been applied wherever possible. Further the uniformity

of the results in different years indicate clearly that in these pure lines we are dealing with strains which are innately superior to the best varieties we have been able to obtain.

The practical significance of using varieties with even a slightly increased yield is shown by a simple calculation. On the average about 140,000 acres of oats are grown in this State each year. If half of this average could be planted to varieties which would yield only two bushels per acre more than those now grown it would mean at the price of 50 cents per bushel an annual increase of $70,000.00 to the farmers of the State over and above what they are now receiving.

Yield of Straw and Other Characters.

Table 9 gives the three year average yield of straw per acre for each line also the average weight per measured bushel and the average days to maturity. In addition to this the average yield of grain as given in table 7 is repeated for comparative purposes.

Table 9.

Average Yield of Straw and Other Characters.

PURE LINES TESTED FOR THREE YEARS.

Line Number.	Grain. Bus. per acre.	Straw. Lbs. per acre.	Weight per measured bushel.	Days to maturity.
Maine 355	86.6	3584	36.8	107
Maine 340	84.5	3907	39.7	103
Maine 281	83.8	3443	37.7	107
Maine 351	81.2	3652	38.0	107
Maine 337	80.5	4019	39.3	103
Maine 230	80.0	3007	37.9	107
Maine 307	79.9	3424	37.2	106
Maine 336	79.9	3794	38.7	106
Maine 346	79.5	3384	38.6	104
Maine 247	78.1	3767	38.2	104
Maine 286	77.9	3909	36.7	106
Maine 357	77.4	3394	36.8	109
Average	80.8	3607	38.0	106

From this table it may be noted:

(1) That there is no definite relation between the yield of straw and grain.

(2) The varieties giving the largest amount of straw are 337, 286 and 340. These are pretty evenly distributed over the table in which the lines are arranged in the order of their yield of grain.

(3) The average yield of straw is 3607 pounds per acre with a range of from 3,000 to 4,000 pounds.

(4) The weight per measured bushel varies from 36.7 to 39.7 pounds with an average of 38.

(5) There is no very definite relation between the weight per bushel and the yield of grain. No. 340 which is one of the best yielding lines gave the highest weight per bushel. On the other hand No. 355 which leads the list as to yield gave one of the lowest average weights per bushel.

(6) The average number of days from planting to harvest is 106 with only slight variations. The seven lines selected from the Banner variety are later than the others. These give an average of 107 days. The Irish Victor lines average to mature in 104 days. This expresses about the average difference in the time of maturity of these two varieties so that in these respects these lines are not different from their original parents.

The actual time to maturity is probably somewhat less than the above figures in ordinary seasons for these averages are unduly affected by the extra long growing season in 1915. Further when grown in large fields these varieties will mature a few days earlier than in our plots. It is always necessary to wait a few days for the marginal plants to mature on a small plot after the center of the plot is ready to cut.

Description of the Pure Lines.

In the preceding section of this paper we have discussed the origin, development and the comparative analysis of the pure lines based upon their quantitative characters, particularly the yielding ability. From the economic point of view the productive power is the most important physiological character of every commercial crop. In this sense the success or failure of the practical breeder naturally depends upon whether he will be able to procure and maintain strains which in their high yield and quality will justify his endeavors. It is, therefore, of great importance for the breeder to have a thorough knowledge of the underlying qualitative characters which are typical of the highest yielding strains and varieties under given environmental conditions.

The importance of these qualitative, or morphological characters may be seen from the fact that they have frequently been considered as directly correlated with physiological characters.

Thus, the Swedish Experiment Station at Svalöf used these morphological characters in its breeding work as a basis for isolating different types, distinguished from each other by different qualitative features. The importance of the morphological external features of the plants, however, must not be overestimated and too much relied upon when undertaking a selection of desirable plants out of commercial varieties. The best looking plant in such a population does not always possess the best physiological qualities. The environment plays an important part and often misleads the breeder. It is not until we undertake a thorough examination of the progeny of a selected plant that we learn its true merits. Nevertheless morphological characters may be a valuable guide in breeding work.

As pointed out in the introduction of this paper, every individual in the progeny of a self-fertilized plant will have the same germinal constitution as every other individual, unless spontaneous germinal changes should occur. Experiments have shown that such changes are relatively infrequent. It has further been shown that certain pure lines can be isolated from some commercial varieties which are far superior to the parent variety in one or more characteristics. It is now of importance to determine whether these physiological characters are related to definite morphological changes in the plant or whether they have occurred independently of changes in these morphological features.

The data given in the following paragraphs are the results of an attempt to find definite morphological characters which might serve to distinguish these pure lines. No attempt has been made to determine the definite correlation between these characters. The question of correlation in oats has been studied by many writers. Tschermak[15] and others have determined the relation between many morphological and physiological characters. Waldron[16] and especially Love and Leighty[17] and

[15]Tschermak, E. v. Fruwirth's Handbuch der. landwirtschaftlichen Pflanzenzuchtung. 2 Auf. Bd. 4, 1910.

[16]Waldron, L. R. A suggestion regarding heavy and light seed grain. Amer. Nat., Vol. 44, pp. 48-56, 1910.

[17]Love, H. H. and Leighty, C. E. Variation and Correlation of Oats (Avena sativa). Part I. Studies showing the effect of seasonal changes on biometrical constants. Cornell Exper. Stat. Memoir No. 3, pp. 1-70, 1914.

Leighty[15] have studied the correlation between various characters in different varieties and different pure lines. In general these studies have shown that there is a high correlation between certain straw and head characters and the yield of grain per plant or culm. It will therefore be of interest to discuss certain of these morphological characters in our pure lines.

The characters of these pure lines may conveniently be classified into two groups, one containing the features studied in the field, the other those analyzed in the laboratory.

The first feature of the young oat plant attracting attention in the field is the *stooling*. By this we understand the ability of the cereals to produce, apart from the main culm, a smaller or larger number of adventitious culms. While a high stooling power is not looked for in dry and continental regions, it is a very desirable feature in this state owing to the abundant precipitation well distributed throughout the growing season. This is particularly true of the central part of this state where the growing season is longer than in the northern part and late maturity of the crop, usually associated with abundant stooling, is not to be feared. The stooling power is influenced by environmental factors such as climate, soil, fertilizer and stand. The stooling qualities of our lines were studied in the garden rows and under field conditions and since they grew under the same environmental conditions the conclusions concerning their stooling ability are comparable.

It has been found that the lines 230, 281, 286, 307, 351, 355 and 357, all originally selected from the Banner variety, tend to show a high stooling power approached only by the lines 340 and 336 of the Irish Victor group. With this vigorous growing tendency is associated a later maturity. The plants of the lines 307, 355, etc., devote, in their early growth, a great amount of growing energy to the production of new culms, while other lines, producing fewer culms, use that energy for the furtherance of their smaller number of heads. This compensation of growth can be clearly seen by comparing the time of heading and maturity of the respective lines.

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[15]Leighty, C. E. Variation and Correlation of Oats. Part II. Effect of differences in environment, varieties and methods on biometrical constants. Cornell Exper. Stat. Memoir No. 4, pp. 81-216, 1914.

It has been found that the difference in the time of heading of the Banner and Irish Victor lines respectively amounts to 7-10 days. This difference is marked in the time of blooming but is even more pronounced towards maturity so that the Irish Victor lines can be harvested several days earlier than the lines 307, 355, etc., of the Banner variety. Line 247, the only representative of the Imported Scotch variety, very nearly approaches the Irish Victor lines in regard to stooling power and maturity. In connection with Table 9 it was pointed out that for the three years the Banner lines averaged to mature in 107 days, while the Irish Victor and Imported Scotch lines each averaged 104 days. In some seasons the difference is much more pronounced than that shown by these averages.

Thus the Irish Victor and Imported Scotch lines may be classified as medium early and those of the Banner variety as medium late. The original parent variety of the Imported Scotch consisted of a majority of rather small, early plants with slender yellow grain and a small per cent of tall, large-grained individuals of a yellowish white color and later maturity. From this latter group line 247 was selected. In regard to stooling ability and maturity the pure lines exhibit a similar behavior to that of their parent varieties.

The *qualities of the straw* are the next characters to be considered. The character of the straw determines the degree of resistance of the plants to wind storms, rains and the influence of rich soil which tend to cause lodging. The importance of the structure and general constitution of the straw under the conditions prevailing in this state does not need to be emphasized. The most important of the straw characters is, therefore, its breaking strength. Several methods have been tried by various investigators in determining this character. One that is very frequently used is to determine the relative amount of force necessary to break a piece of the dry straw of a definite length[19]. Some attempts were made to determine this breaking strength but the results obtained with the dry straw did not agree with field observations as to lodging. Consequently the attempt was abandoned.

Various investigators have also studied the anatomical structure of the culm and the amount of mineral substance

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[19]Leighty, C. E. Loc. cit.

deposited in the straw in the attempt to find a relation between those characters and the lodging of the plants. For practical purposes under conditions facing the plant breeder in his selection work, these methods can not be taken into consideration. It has seemed to us more satisfactory to rely chiefly upon experience and observations made directly in the field. The study of the actual conditions in the field, the notes taken after heavy storms and rains served in our selection work as a very valuable guide in the process of elimination of undesirable strains. Consequently under ordinary soil conditions the 12 ultimately selected lines show a very considerable resistance and strength of straw. This was shown very clearly in the season of 1915 when the very heavy flooding rains in the latter part of the season caused much damage in the central part of the state. In our plots those commercial varieties which were inclined to lodge were in very bad condition at harvest. None of these pure lines were seriously damaged. Several of the Banner lines, especially 357 and 355, lodged to some extent. The Irish Victor lines all stood up well. No. 340 was grown as a farm oat at Highmoor and on the entire 13 acres there was only one small area that lodged at all. Of the pure lines, Nos. 355 and 357 showed the greatest amount of lodging.

Some data with regard to the height and diameter of straw of the pure lines are given in Table 10. These data represent the means of measurements of a considerable number of individuals collected at random in the different field plots. It will be noted from this table that the pure lines also show only a slight variation in the height and diameter of the straw.

In regard to the *color and width of the leaves* the pure lines show again a resemblance to their respective parent varieties. The Banner lines have slightly wider and darker leaves than the Irish Victor lines.

CHARACTERS OF THE HEAD.

The panicle or head of the oat plant contains a series of very important features which determine the qualitative and quantitative merits of the plant. The type of head is therefore a most important character and a very reliable guide in selection and breeding work. The head characters serve to isolate different forms and types of oats and on that basis the Svalöf

Experiment Station has founded a system of oat varieties. In the recent classification of oat varieties proposed by Böhmer[20] the type of head has also been used as a distinguishing basis together with the grain characters, thus combining the system of the Svalöf Experiment Station based upon the head types with that of Atterberg[21] founded upon the grain characters. The type of the oat head has also been found to be correlated with quantitative characters. Thus at Svalöf the spreading type of head with drooping branches is considered as correlated with a small yield of grain.[22]

The pure lines dealt with in this paper belong to the vast group of oats with spreading heads. Here again they show a resemblance to the predominating types in their respective parent varieties. The description of the head characters of the pure lines will be aided by referring to figures 19 to 24. These photographs were taken shortly before maturity and all on the same day. The head types of the Banner lines fall within the group of the stiff-branched heads. As will be seen from figures 19, 23 and 24 the Banner head is chiefly characterized by its vigorous, stiff, ascending branches forming a very narrow angle with the main axis of the head. This is especially true of the first branches in the lower whorl. The position of the branches with respect to the main axis and the angle which they form with the latter determine the character of the head. Although with the approaching maturity the increasing weight of the spikelets tend to bend the branches away from the main axis, the characteristic upstanding habit can still be clearly seen. In the early growth and especially when allowed a wide stand this habit is considerably more pronounced. The branches of the Banner head are vigorous, medium long and well covered with spikelets. The main axis of the head is straight and well covered with spikelets at its top, which is a desirable feature since the grain develops and matures best at the top of the main axis and at the tips of the branches. The

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[20]Böhmer. Über die Systematik der Hafersorten, Berlin, 1909.

[21]Atterberg, A. Neues System der Hafervarietäten. Landwirtschaftl. Versuchstationen. Bd. XXXIX, Berlin, 1891.

[22]Cited from Fruwirth: Züchtung der landw. Kuturpflanzen, Bd. IV, p. 354, Berlin, 1910.

head of the Banner oat has a tendency to distribute its branches in such a manner as to leave a part of the circumference vacant or filled only with one or two branches. Thus the Banner head is not perfectly symmetrical. This lack of symmetry is still more intensified by the different angles which the branches in the different whorls form with the main axis.

While the Banner oat has a typical stiff-branched head, the pure lines of the Irish Victor variety show characters of a transitional type of head. A comparison of figure 19 with figure 20 clearly shows the difference between the two types. The panicle of the Irish Victor lines suggests a greater symmetry caused by the more proportionate dimensions of the branches and the more uniform angles between the branches and the main axis. It will be noted that the branches are more drooping, thus causing the head to appear shorter and more extended on its circumference. The branches of the Irish Victor head spread more symmetrically about the whole circumference and are somewhat finer than those of the Banner oat. The main axis ascends straight upwards and is rich in spikelets at the top.

The type of head of No. 247 of the Imported Scotch variety shows still more clearly the drooping habit. The general picture of this type is given in figure 22. The head is markedly smaller than that of the two former types, the branches are shorter and decidedly more drooping. The main axis is straight but with a slight tendency to bend over at the top. The branches are proportionate and symmetrically spreading.

While the figures 19 to 24 give the general appearance of the three types of head, a closer analysis of the details of these head characters is shown in Table 10.

This table does not include all the 12 lines. However it contains the best representatives of the three types. The given data represent the means of measurements of a number of individuals of each line. From this table it may be noted that there is a correlation between the length of the head and the total number of spikelets. This correlation and several others have been established by v. Tschermak[23] and by Love and Leighty. It has been shown that with an increase in the length of the head there is a corresponding increase in the number of

[23]Cf. Fruwirth, *loc. cit.*, p. 332.

whorls, the number of spikelets in the lower whorl, and the length of the longest branches in the lower whorl.[24]

Line 355 which leads the list as to yield ranks also highest with regard to all these head characters, while line 247 occupies the lowest rank of the table.

The lines 355 and 307 of the Banner variety show the highest values for the length of head and for the length of the longest branch in the lower whorl. This correlation of the longest branch in the lower whorl is also illustrated by Line 351.

TABLE 10.

Data on Certain Straw and Head Characters.

Line number.	PARENT VARIETY	Height of main culm.	Diam. of straw.	Length of head.	Length of longest branch in lower whorl.	Distance from lower to next whorl.	No. of whorls.	No. of spikelets in lower whorl.	Total number of spikelets.
		cm.	mm.	cm.	cm.	cm.			
Maine 355	Banner.........	138.6	41.3	22.0	12.4	5.9	6.0	10.8	37.3
307	Banner.........	132.9	39.4	21.2	12.6	5.6	5.7	10.3	33.6
351	Banner.........	132.5	41.7	20.5	12.0	5.7	5.4	9.8	32.4
340	Irish Victor.....	133.9	40.4	20.7	11.7	6.0	5.6	10.1	32.1
336	Irish Victor.....	138.6	41.3	21.0	11.3	5.7	6.0	8.3	32.8
346	Irish Victor.....	133.9	42.9	20.6	11.7	5.6	5.8	10.5	33.4
247	Imported Scotch	133.7	40.4	19.7	10.9	5.3	5.0	9.9	30.4
	Average....	*134.9*	*41.1*	*20.8*	*11.6*	*5.7*	*5.6*	*10.0*	*33.2*

GRAIN CHARACTERS.

With pure lines selected chiefly for high yielding ability out of only three more or less related commercial varieties the grain will naturally not show many striking botanical characters that would serve as a basis for classification. Furthermore, the three groups of the pure lines resemble in respect to external grain characters their respective parent varieties so that the

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[24]It is realized that the material from which these data have been obtained is comparatively small and that the analysis of a large number of plants would bring out these relations more clearly and smooth out the irregularities.

question of shape of kernel is reduced to the distinction of possibly three types. The grain of the Irish Victor lines is of medium size, of a pale yellow color with a slightly reddish hue. It is nearly cylindrical, well filled, and bluntly pointed. The glumes are smooth and lustrous. There is no trace of pubescence on the base or back of the grain. The awns, which are in general a very variable character, appear very infrequently on the glumes of the Irish Victor grain. On the average there are only one or two awns per culm. The spikelets contains as a rule two kernels.

The type of kernel of Line 247 very closely resembles that of the Irish Victor lines.

The Banner lines have a rather coarse kernel of lighter, almost pure white color, slightly oval and more pointed than the Irish Victor. The glumes are a little coarses than those of the Irish Victor grain and have not the glossy appearance of the former type. They show a greater tendency to develop awns.

While there are only a few distinguishing qualitative features of the grain of the pure lines, a greater difference and variation is exhibited by the quantitative characters of the kernels.

The relation between the three dimensions of the oat kernel have been recognized as a valuable distinguishing character. They were introduced by Körnicke and Werner[25] and also used for systematic purposes by Atterberg[26]. Danaiffe and Sirodot[27] and Böhmer[28]. The methods used in measuring the length, width, and thickness of the kernels of our lines differed from those followed by the above named authors. They measured the grain as a whole, i. e., enclosed in its hulls, while the data given in Table 11 refer to measurements of the hulled, naked kernel, i. e., the caryopsis itself.

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[25]Körnicke, F. and Werner, H. Handbuch des Getreidebaues. Berlin. 1885.

[26]Atterberg, A. *Loc. cit.*

[27]Denaiffe and Sirodot. L'avoine, Paris. 1901.

[28]Böhmer, —. *Loc. cit.* p. 26.

TABLE II.

Relation between the three dimensions of the hulled kernels of the pure lines.

LINE NUMBER.	Length mm.	Width mm.	Thickness mm.
Maine 340	9.11	2.38	1.96
Maine 337	9.09	2.41	1.97
Maine 336	9.13	2.37	1.93
Maine 346	9.15	2.44	1.95
Maine 230	8.99	2.31	1.99
Maine 281	8.98	2.36	1.94
Maine 355	8.87	2.25	1.87
Maine 286	8.96	2.32	1.87
Maine 351	9.14	2.29	1.90
Maine 307	9.04	2.30	1.93
Maine 357	9.02	2.35	1.96
Maine 247	8.85	2.38	1.94
Average	*9.03*	*2.35*	*1.93*

In using this method an attempt has been made to determine whether the relations between the three dimensions of the naked kernel might not furnish a reliable index that would allow a distinction between the kernels of even closely related strains. From an economical standpoint the measurement of the naked kernel would be justified, since in many cases the hulls or glumes obscure the real merits of the kernel proper, which alone determines the value of the grain. It is admitted that the measurement of the naked kernels involves the technical difficulty of hulling the grain. However, any closer study of the grain characters requires the determination of the hull percentage and the hulled kernels prepared for that purpose can be used for the measurements. It is realized that this method has some points to be determined yet and it is proposed to test further its validity by analyzing a larger material from different years and working up the data statistically.

In the present case, however, the data have been found rather interesting and have a comparable value, since they refer to kernels of plants grown in the same year and under the same environmental conditions. The measurements were carried out with the aid of a micrometer caliper. The measurements were recorded to hundredths of a millimeter. In Table II the lines are arranged according to their parental varieties. It will be noted that there is a marked distinction between the three groups of the lines. The first four lines of the Irish Victor show throughout higher

values for all the three dimensions than the Banner lines and line No. 247. Their values are pretty close and indicate a fluctuation about the mean of the original type. This is true also of the majority of the Banner group. Lines No. 351, 307 and 357 show higher values for the length and thickness than the other four Banner lines and approach in this respect the Irish Victor lines but they rank decidedly lower than the latter with regard to width. The data in this table enable us to distinguish more clearly the types of kernel of the three line groups than would be possible by an inspection of the kernels enclosed in the hulls. The Irish Victor lines develop on the whole a longer, wider and thicker kernel than the majority of the Banner lines. Line 247 has the shortest kernel but the relation between width and thickness approaches that of the Irish Victor lines.

A further important quantitative character of the grain is *The weight of the kernel.* The *absolute* weight of a number of kernels is the most reliable measure of the quality of the grain. The weight of a given volume of grain is generally considered as unsatisfactory, especially with regard to oats. Neither does the specific weight furnish reliable values as has been shown by Wolny.[29]

TABLE 12.

Weight of grain and hull percentage.

Line Number.	PARENT VARIETY.	Weight per 1000 kernels.	Weight of 1000 naked kernels.	Calculated weight of hulls from 1000 kernels.	Hull percentage.	Rank in order of the hull percentage.
		gms.	gms.	gms.		
Maine 340	Irish Victor...............	40.30	29.02	11.28	28.00	4
Maine 336	Irish Victor...............	39.38	28.16	11.22	28.50	8
Maine 247	Imported, Scotch..........	39.38	28.09	11.29	28.77	9
Maine 337	Irish Victor...............	39.76	27.78	10.98	28.32	5
Maine 357	Banner....................	38.16	27.33	10.83	28.37	6
Maine 346	Irish Victor...............	37.61	26.36	11.23	29.87	12
Maine 281	Banner....................	37.48	26.67	10.81	28.83	11
Maine 351	Banner....................	36.84	26.58	10.26	27.84	2
Maine 286	Banner....................	36.71	26.14	10.57	28.78	10
Maine 307	Banner....................	36.40	26.05	10.35	28.44	7
Maine 230	Banner....................	36.10	26.01	10.09	27.95	3
Maine 355	Banner....................	35.49	25.64	9.85	27.76	1
	Average..............	*37.72*	*26.99*	*10.73*	*28.15*	–

[29]Cited from Böhmer. *Loc. cit*, p. 24.

Table 12 gives in the third column the weight per 1,000 kernels of the respective pure lines. In determining this weight the general method of using only the lower or larger kernel of the spikelet was followed. It is obvious that it is necessary to use the same form of kernel throughout the measurements when comparative values are sought.

From Table 12 it is noted that the lines of the Irish Victor group and Lines No. 247 rank highest as to the weight per 1,000 kernels. It is interesting to note that the highest yielding line, No. 355, shows the lowest kernel weight.

Hull percentage. The economic value of the oat is determined by the naked kernel and it is, therefore, of importance to determine what part of the grain as a whole is made up by the hulls. From Table 12 it will be seen that the hull percentage does not quite parallel the weight per 1,000 kernels. Thus Line No. 346 ranks lowest as to hull percentage while it occupies the sixth place with regard to kernel weight. Similar points are noted for Lines No. 281 and No. 286. Line No. 340 has a comparatively low hull percentage considering its high weight per 1,000 kernels. Line No. 355 shows the lowest hull percentage.

Table 12 also gives the data regarding the relation between the weight of the naked kernels and the hulls. The weight of hulls of 1,000 kernels has been calculated from the hull percentage and weight per 1,000 kernels (Cf. Böhmer, *loc cit.*, p. 35). The lines 247, 340, 336 and 346 have the highest absolute weight of the hulls. While with the three first lines named the high weight of the hulls is balanced by the high weight of the naked kernels with Line No. 346, the high relative and absolute weight of the hulls is not followed by a corresponding high weight of the naked grain. Line No. 355 has the lightest hulls and Line No. 247 the heaviest.

To complete the description of the pure lines a few data may be given with regard to the germination of the grain. The germination tests were carried out in two series with 200 kernels of each line.

The results given in Table 13 do not show any great variation in the percentage of the germinated kernels of the pure lines. The total average for all the lines is 98.9 per cent which indicates a very high germination quality.

TABLE 13.

Germination Test of Pure Lines.

Line Number.	Number of Germinated Kernels.		Percentage of germinated kernels.
	Series I.	Series II.	
Maine 247	199	200	99.8
Maine 351	200	199	99.8
Maine 340	199	199	99.5
Maine 286	200	198	99.5
Maine 336	200	198	99.5
Maine 346	198	199	99.3
Maine 281	197	200	99.3
Maine 357	198	199	99.3
Maine 307	198	197	98.8
Maine 230	196	198	98.5
Maine 355	199	194	98.3
Maine 337	192	192	96.0
Average	198.0	197.4	98.9

The preceding description of these pure lines has shown very clearly that there are no marked morphological differences between these pure lines and their respective parent varieties. In the discussion of the majority of the characters, e. g., stooling, type of head and of grain, it has been necessary to deal with groups of the pure lines corresponding with their parent varieties. On the other hand, there is a large amount of evidence which indicates that in such characters as yielding ability and strength of straw these pure lines are distinctly superior to their parent varieties.

The modern view of the hereditary processes indicates that separate characters are inherited as units or as groups of units. It is, therefore, conceivable that at some time in the history of the parent varieties, spontaneous germinal changes occurred which affected the hereditary yielding ability of a certain plant. Such changes might or might not be accompanied by changes in one or more morphological characters. Further, such a spontaneous germinal change might result in either an increase or a decrease in the yielding ability. In the process of selection and elimination as outlined in this paper naturally only the variations in the direction of an increase would be preserved.

That variations do occur which tend to yield less than the parent varieties is indicated by the so-called "running out" of varieties. A variety which has been grown for many years without any attempt at improvement often shows a large num-

ber of undesirable, low yielding plants. Such a variety is said to be "run out." This condition undoubtedly results from the chance preservation and multiplication of germinal variations in the direction of low yield. With care to avoid mixing and the occasional selection of seed in the field, it is possible to avoid the undue multiplication of these undesirable types and hence to avoid the so-called "running out" of varieties.

That germinal variations similar to the above do occur in the case of morphological characters has been clearly shown by Nilsson-Ehle[30]. He was able to show that in pure breeding strains and under conditions in which there was no chance of mixing, grains appear which differed either in their color or in the character of their grain. These variations either bred true at once or after one or two generations the great majority of their progeny bred true to their new characters. The existence of these well authenticated cases of germinal variation in morphological characters makes it almost certain that similarly inherited variation may occur in respect to physiological characters such as yield.

The frequency with which such variations occur is unknown but experiments indicate that they are relatively very rare. Likewise the underlying cause of these germinal variations is unknown. The evidence indicates that they are probably not due to hybridization. They probably belong to the class of mutations as defined by de Vries.

In the case of self-fertilized plants such as oats, wheat, beans, etc., there is a large amount of evidence to indicate that when once acquired these new characters will breed true. It is these germinal variations in respect to yield and to strength of straw that we have attempted to isolate. The evidence from the three year tests indicates that we have been successful with these twelve pure lines, or with the majority of them at least. At the same time it is clear that these variations in yield have not been accompanied by any marked morphological changes in the characters studied.

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[30]Nilsson-Ehle, H. Über Fälle spontanen Wegfallens eines Hemmungsfaktors beim Hafer. Zeit. f. indukt. Abst.—u. Vererbungslehre, Bd. 5. pp. 1-37, 1911.

————————. Spontanes Wegfallen eines Farbenfaktors beim Hafer. Verh. d. naturf. Vereins in Brünn, Bd. 49, pp. 139-156.

Discussion and Conclusions.

After the discussion of the various characters and qualities of these pure lines we come to the practical question as to which is the best. It has been clearly brought out in the paper that under Highmoor conditions all of these twelve pure lines possess desirable qualities. If that had not been the case they would have been discarded. While under our conditions one or two of these lines have appeared to be especially good, it is not at all certain that under other conditions some of the other lines might not prove as good or better. It is certain that any one of these lines is capable of producing a much better yield of oats than the varieties commonly grown in the state.

In this connection, however, we desire to say that if these or any other varieties are sown on wornout land without proper fertilization, or if the seed bed is poorly prepared, good yields cannot be expected. A circular giving the exact methods used in growing oats on our two farms will be sent to any resident of the state on request. It will be seen from this circular that the methods used by us are only such as can be employed by any intelligent farmer.

Of the twelve pure lines we have chosen No. 340 as the best for Highmoor conditions. As shown in Table 7, this variety stands second in average yield for the three years. It has a very stiff straw and even under very severe tests has shown practically no lodging. In this respect it has appeared superior to No. 355 which gave a higher average yield. Further No. 340 has a very good white grain and a high weight per measured bushel. It has the highest weight per 1,000 grains of any of the pure lines. It has a relatively low hull percentage. It shows a relatively small amount of variation in the yield of its four 1915 plots (Table 6).

In 1914 this line was grown in a field test plot about three-quarters of an acre in area. It gave a yield of 86 bushels per acre. In 1915 this pure line was grown as a farm oat at Highmoor. While the area was not accurately measured, there were about 13 acres. The average yield was about 75 bushels per acre. In the variety test plots Maine 340 has averaged for the three years to yield 9.3 bushels per acre more than its parent variety, the Irish Victor, during the same time. Further, as may be seen from Tables 7 and 8, this difference in yield be-

tween this pure line and its parent variety has been very consistent in each year.

Maine 355, a Banner selection, probably stands as second choice. This pure line averaged to yield about two bushels per acre more than No. 340 for the three years. However, this higher yield is offset by certain other characters. Thus No. 355 is a little more likely to lodge on very rich soil, or in very wet seasons. It is not weak-strawed, but yet it does not have quite the same resistence as No. 340. No. 355 also showed a relatively high variation in the yield of its 1915 plots. It has a relatively low bushel weight and a low weight per 1,000 kernels. It has, however, given the highest average yield of any of the pure lines. Its average yield is seven bushels above the average of its parent variety for the same years. It also has the lowest hull percentage of any of the pure lines.

Maine 247, from the Imported Scotch variety, and Maine 286 and 357, from the Banner variety, are the least promising of these pure lines when grown under Highmoor conditions.

The remaining seven lines, Nos. 281, 351, 337, 230, 307, 336 and 346 show comparatively slight differences in yield. No. 337, an Irish Victor selection, has proved very variable in yield in the different years. In 1913 it gave a very low yield and in 1914 a very high yield. In 1915 its yield was about the average of the pure lines. While there are some differences in minor characters between the other pure lines, these differences are not of sufficient importance to warrant further discussion.

Another point which should be emphasized in connection with pure line varieties in general is the evenness with which the plants ripen. The relative time from planting to harvesting is an inherent characteristic of different varieties and different strains. In many ordinary commercial varieties there are some plants which ripen much earlier than others and likewise some that ripen very late. The casual observer is not likely to notice this difference but a closer inspection of individual plants shows that this is the case in many varieties. The plants which ripen first are likely to be too ripe when cut and will tend to shatter, thus cutting down the yield. Plants which are late in maturing will be slightly green when cut. Grain from such plants will tend to injure the appearance of the

entire lot of grain. Further such immature grain will tend to lower the weight per bushel and likewise the yield.

All the plants of a pure line, since they are the descendants of a single original plant, will have the inherent tendency to ripen at the same time. This is one of the factors which leads to increased yields with pure line varieties. Of course, environmental conditions may greatly influence the time of ripening so that unless a field is reasonably uniform in the character of its soil there will always be some difference in maturity in different parts of the field. However, insofar as this matter can be remedied by seed, the pure line varieties offer a distinct advantage over the ordinary commercial varieties.

It is planned to continue the majority of these pure lines in our test plots until such time as newer and better lines shall be obtained. A large number of new selections are being tested at the present time. These will be tested along with the best of the pure lines described in this bulletin and also with a selected list of commercial varieties.

In order that these pure lines may be tested by the farmers of the state, arrangements have been made with the Extension Department of the College of Agriculture to place the limited amount of seed of each line in the hands of representative farmers. The arrangements are that the farmer shall grow one of these lines for at least two years in order to give it a satisfactory test. Seed from these lines which prove satisfactory in their respective communities is to be offered for sale at a reasonable price. It is hoped that this arrangement will secure a distribution of the seed of such of these pure lines as prove themselves worthy. Maine 340 will continue to be grown as a farm oat at Highmoor and the surplus seed offered for distribution.

Summary.

In the introduction to this bulletin the meaning of a pure line is defined and illustrated. The general methods used in the pure line breeding of cereals are also discussed.

The work with which this paper deals was begun in 1910. In that year 460 individual oat plants were selected from 18 different commercial varieties. In 1911 seed from 188 of these plants was grown in short garden rows.

On the basis of the results thus obtained 80 of these rows were thought good enough to be continued in small plots. Duplicate 1-2000 acre plots of each of these 80 pure lines were grown in 1912.

Of these pure lines 34 were sufficiently promising to be continued into field tests in 1913. Thirty-one of these were again tested in 1914.

In 1915 all of these pure lines were discarded except twelve. These twelve lines were tested in quadruplicate plots in 1915.

In each of the three years, 1913-1915, these pure lines were grown along with a number of the best commercial varieties obtainable. In 1914 and 1915 the pure line plots alternated in the field with commercial variety plots.

A method of correcting the yield of individual plots for differences in soil fertility is briefly outlined. This method of correction was applied to the 1914 and 1915 results and the major portion of the discussion is based on these corrected yields.

The detailed results of the field tests of these pure lines for each of the three years is given in tables 3, 4 and 5. The results so far as yield is concerned are summarized in table 7. In table 8 are summarized the results of tests of eleven commercial varieties tested for the three years under the same conditions as the pure lines.

From these tables it is seen that the 12 pure lines averaged to yield 80.8 bushels per acre against 75.2 bushels for the 11 commercial varieties. Only four of the commercial varieties gave a better yield than the poorest of the pure lines. In all cases the average yield of the pure lines selected from a given variety exceeded the yield of the parent variety.

While the original selections represented 18 different varieties, the pure lines finally retained came from only three different varieties. Seven of these are from the Banner variety, four from the Irish Victor and one from the Imported Scotch.

A detailed description of the 12 pure lines shows that in morphological characters, such as type of head, character of the grain, etc., these pure lines closely resemble their respective parent varieties. The changes in the physiological characters which result in higher yield are therefore not necessarily associated with morphological characters in the plant or grain.

Of the 12 pure lines, Maine 340, an Irish Victor selection is regarded as the best for Highmoor conditions. This line stood second in average yield but it possesses an especially stiff straw, a high weight per bushel and per 1,000 kernels and a relatively low hull percentage.

Maine 355, a Banner selection, is second choice. It gave the best average yield of any of the lines. It has a slight tendency to lodge on heavy soil. This variety is especially recommended for planting on lighter soils.

Maine 247, 286 and 357 appear to be slightly inferior in yield to the other pure lines. Between the remaining lines there is little to choose so far as the tests at present show.

Each of these 12 pure lines is well adapted to conditions in the southern and central part of the state. Being bred from single plants they tend to ripen much more evenly and are more uniform in all their characters than most commercial varieties. These 12 varieties represent the best out of 460 original selections.

We are satisfied that the use of any of these pure lines will result in increased yields over those obtained with most commercial varieties. Steps are being taken to secure the distribution of seed of these pure lines to the farmers of the state.

Fig. 19. Typical Heads from Maine 355
Fig. 20. Typical Heads from Maine 340

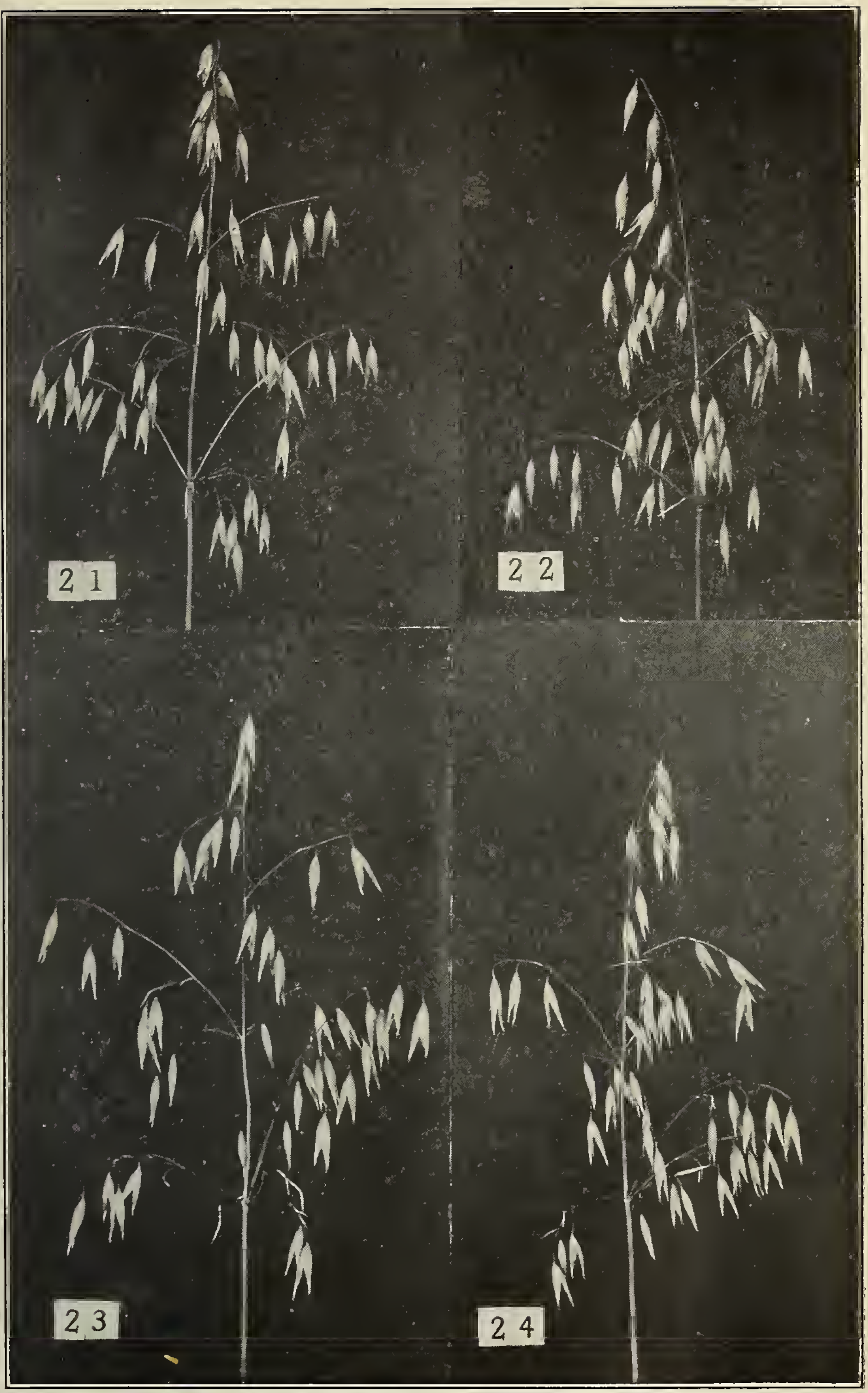

Fig. 21. Typical head from Maine 337
Fig. 22. Typical head from Maine 247
Fig. 23. Typical head from Maine 357
Fig. 24. Typical head from Maine 230

[illegible]